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SIMULATION AND EVALUATION OF DECENTRALIZED

AMBULANCE SYSTEMS WITH HELICOPTERS

A THESIS

Presented to

The Faculty of the Graduate Division

by

Walter J. Chrobak

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SIMULATION AND EVALUATION OF DECENTRALIZED
AMBULANCE SYSTEMS WITH HELICOPTERS

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SUMMARY

The objective of this research was to develop and test a simulation model with which to test a decentralized system of ambulances with a provision for the addition of helicopter ambulances. Data for the simulation was obtained from Grady Memorial Hospital in Atlanta, Georgia.

The simulation uses a grid coordinate system for both locating ambulances, calls, and satellite locations, and for the measurement of distances between items of interest.

In general the simulation produced no significant reason for rejection of the model. Decentralization of ambulances was shown to reduce average service time and the number of ambulances needed in the system. The use of helicopter ambulances further reduced this service time and also provided a more efficient utilization of ground ambulances in the system.

CHAPTER I

INTRODUCTION

Objective

The objective of this research is to develop and test a simulation model to be used in the analysis of a metropolitan ambulance system. More precisely, the model will be used to examine several alternatives to the presently existing system of centrally located ambulances, and by using available statistical data and simulation procedures determine whether or not a reduction in service time can be achieved by using these alternatives. Helicopter ambulances will be included in at least one alternative system. Pertinent factors considered include the effects of weather on helicopter availability, maintenance scheduling, accident rates and location, and ambulance location.

Specific Methodology

The analysis will be accomplished in three basis phases. In phase one statistical data will be used to simulate a system similar to that presently existing at Grady Memorial Hospital in Atlanta, Georgia. Grady provides an example of a centrally located hospital serving primarily a metropolitan area but with additional responsibility for a surrounding rural community. At present Grady serves Fulton and DeKalb counties with a force of ten ambulances. Six ambulances provide continual service while the remaining four are used as replacements when maintenance is necessary. The purpose of phase one will be to obtain a base of service times and the number of ambulances needed in a centralized system. The service time and ambulance number will be used in comparison with other systems to be simulated.

Phase two will be a simulation of a decentralized system. Rather than having all ambulances operate directly from a central hospital, this system will place four ambulances in satellite locations based on an evaluation of the distribution of calls received. Two ambulances will remain at the central hospital thus bringing the total number of ambulances initially in the system to six. As the distance from the location of a remote request for ambulance service will in general be less for a satellite ambulance than for an ambulance located at the central hospital, it may be assumed that a reduction in service time will be achieved. A simulation of this concept will provide more positive evidence and the magnitude of this time reduction.

Phase two will be accomplished in two parts. In part one calls received in a particular sector will be answered by the ambulance serving that sector. If the sector ambulance is not available, a queue will be permitted to form in that sector. Part one will primarily provide a minimum service time with which to compare other service times. The design of the system in part one will allow no movement of ambulances between sectors. It is recognized that this will result in an extremely inefficient system in terms of the number of ambulances needed if queues are not desirable. This directly suggests part two of phase two.

In part two the sectors will be retained but a priority system will be established. If a sector ambulance is not available when a call is received then the closest ambulance to that call will answer regardless of sector. As with the centralized system the number of ambulances in the system will be varied.

Finally, phase three will introduce the helicopter ambulance into the decentalized priority system. Initially the system will start with one helicopter though this number will be varied. A two step concept of helicopter evacuation will be used. In areas some distance from the central hospital satellite helipads will be added to the model. A call from these remote areas will result in the dispatching of a satellite ambulance. This ambulance will transport the patient to the nearest helipad where a concurrently dispatched helicopter will provide air evacuation directly to the hospital.

In the interest of economy all helicopters will operate directly from the central hospital and the number of helicopters used will be kept to a minimum. Direct hospital to patient to hospital helicopter evacuations will not be simulated or examined.

The three simulations or phases will then be analyzed in terms of service time and ambulance utilization. Service time will be defined as the time from which an ambulance is dispatched until the patient causing the call has arrived at the hospital (Figure 3). The feasibility of the decentralized and helicopter modifications of the current system will be dependent on the magnitude of reduction of this service time and the number of vehicles needed to bring about this reduction.

No method of optimally locating the satellite ambulances or helipads will be provided in this simulation. Instead it is hoped to show that even the most primitive geometric stationing of satellite ambulances and helipads based on call occurrence rather than hospital convenience will provide a reduction in average service time.

Literature Search

General Discussion

A large number of articles relating to the use of the helicopter for evacuation of civilian patients have recently been published. This increased interest is in large measure probably due to the unprecedented success of aeromedical evacuation in the Vietnam War. It has been estimated that in rural areas two helicopters could provide a faster, less expensive service than eight more ambulances (12).

In general, the literature available which has examined the civil use of the helicopter ambulance has proposed and examined systems in which the helicopter was flown directly to the accident scene to accomplish a required evacuation. This system is of course limited by an area in which the helicopter can be landed and therefore finds major limitations in densely populated areas such as the downtown area of a city. A recommendation of the Air Medical Evacuation System (AMES) Study by Arizona State University was that the helicopter ambulance be used primarily as a rural and remote area system where its speed, observation capability, and accessibility to remote locations could be used most effectively (1).

The concept of flying the air ambulance directly to an accident or patient scene provides three areas of further study. As previously mentioned a suitable landing area becomes a requirement for utilization of the helicopter. The size of the landing area required depends on several factors. The physical size of the aircraft, the horsepower of the machine, wind, temperature, altitude, and the load are only some of the items that must be considered. Any one of these factors may prevent the straight up takeoff or straight down landing that is generally associated with the helicopter, and which are necessary for operations in confined areas. The AMES Report noted an unexpected result in the selection of suitable helicopter landing areas. In several cases people on the ground, unaware of the capabilities of the helicopter selected landing sites at a greater distance from the actual evacuation scene than was necessary (1).

It must be recognized that in some cases no landing site will be available. Two alternatives then exist. The patient can be evacuated by ground vehicle to a suitable location for transfer to a helicopter, or a litter and hoist can be used for evacuation. The litter and hoist method, though frequently used in combat situations, presents several problems.

As of December 1969 it was reported that there was no standard or commercially available litter that could be lifted by hoist and provide the protection and comfort necessary to the patient. The Army Combat Developments Command was at that time testing a litter basket designed to give patient protection, a quick change capability, and one that could be used with only limited training being needed by the using air crew (3). A rescue collar of the type used by the Coast Guard is another possibility, but this device requires the cooperation of the injured party. This cooperation may not always be possible. Hoisting operations will necessarily require a helicopter of sufficient size, power, and hence greater cost, to permit hovering out of ground effect, internal space for manipulating the litter basket, and design to permit the mounting of the hoist. Add to this the unsettling effect of the experience of being helplessly hoisted into the air for perhaps one's first ride in a helicopter, and the inherent noise and rotorwash typical of helicopter operations, and it is easy to see why at least one hospital official is opposed to litter and hoist evacuations (9).

A second consideration that must be included in helicopter evacuation directly from the patient scene is that of weather. It must be recognized that certain weather conditions will prevent helicopter operations. If existing conditions provide less than one mile visibility the helicopter cannot legally be operated under Visual Flight Rules in controlled airspace. It may fly outside controlled airspace at 1200 feet or less above the ground surface at a speed that allows the pilot adequate opportunity to see other air traffic or other obstructions in time to avoid a collision (5). At sixty miles per hour one half mile visibility gives the pilot 30 seconds to react to a fixed obstacle. While the helicopter may be restricted by weather that has no effect on an ambulance, the opposite may also be true. In deep snow a helicopter may be able to fly while an ambulance might have to wait until roads are clear. Finally, the helicopter can be operated under Instrument Flight Rules when weather conditions present zero visibility and ceiling. In this case, the only limitation is the requirement for some minimum visibility and ceiling at the aircraft's destination, and depends on the type of instrument approach available.

The last restriction that will be mentioned with regard to the direct evacuation system being discussed is that of helicopter range. This will again be dependent on the type of helicopter being used. For this discussion, the range of the helicopter will be the distance that it can fly to a required patient evacuation and return to the hospital without refueling. Using a Hiller FH-1100 helicopter in their study, the Air Medical Evacuation System selected an operating radius, or range, for their helicopters of 150 miles (1).

The three restrictive areas just discussed were emphasized for a definite purpose. In the model proposed by this thesis, a two step method of helicopter evacuation will be used. As was previously mentioned, this method will involve transporting the patient from the accident scene or other location to a selected site for pick up and evacuation to the hospital by helicopter. This system will eliminate the need for litter and hoist operations, remove the problems encountered in confined area operations, and should the proposed pickup site be equipped with a radio beacon and appropriate instrument approach procedure, remove at least part of the helicopter weather restriction.

Further the two step method will in effect increase the operating radius of the helicopter system. This is best illustrated by again referring to the Air Medical Evacuation System Study. The AMES project attempted to provide helicopter evacuation to the entire State of Arizona. It was determined that the 150 mile operating radius of the helicopter prevented complete coverage of the state and therefore more than one helicopter service would be necessary. Using two zones of operation it was found that all but 8.94 percent of non-urban casualties could be serviced.

In Figure 1 the center of the two sectors used in the AMES Study are indicated by points A and B and their area coverage is shown by the dashed circles. Areas not receiving coverage under this system are crosshatched.

The AMES Study further estimated the cost of one ambulance plus appropriate medical equipment to be $13,500 and its speed when answering a hypothetical call was assumed to be 50 miles per hour. The cost of one helicopter ambulance plus appropriate medical equipment was similarly found to be $118,458 and the helicopters hypothetical speed was assumed to be 90 miles per hour. Thus for the cost of one helicopter roughly eight ambulances could be purchased. Additionally, in one hour and forty minutes the ambulance could travel 83 miles at 50 miles per hour while the helicopter could travel 150 miles at 90 miles per hour (1).

Again Figure 1 shows the establishment of one central helicopter sector at point C and its area coverage by the solid circle. If eight satellite ambulances are positioned at points one through eight with each having an operating radius of 83 miles the areas not receiving coverage are indicated by shading. It is obvious that more complete coverage is provided by the satellite or two step system. Each of the eight satellite ambulances can pick up a patient within its sector and deliver him to a pick up point on the circumference of the helicopter sector with minimum waiting time for the ambulance to helicopter transfer. The cost of satellite garage facilities for the eight ambulances or the cost of establishing a second helicopter sector have not been considered.

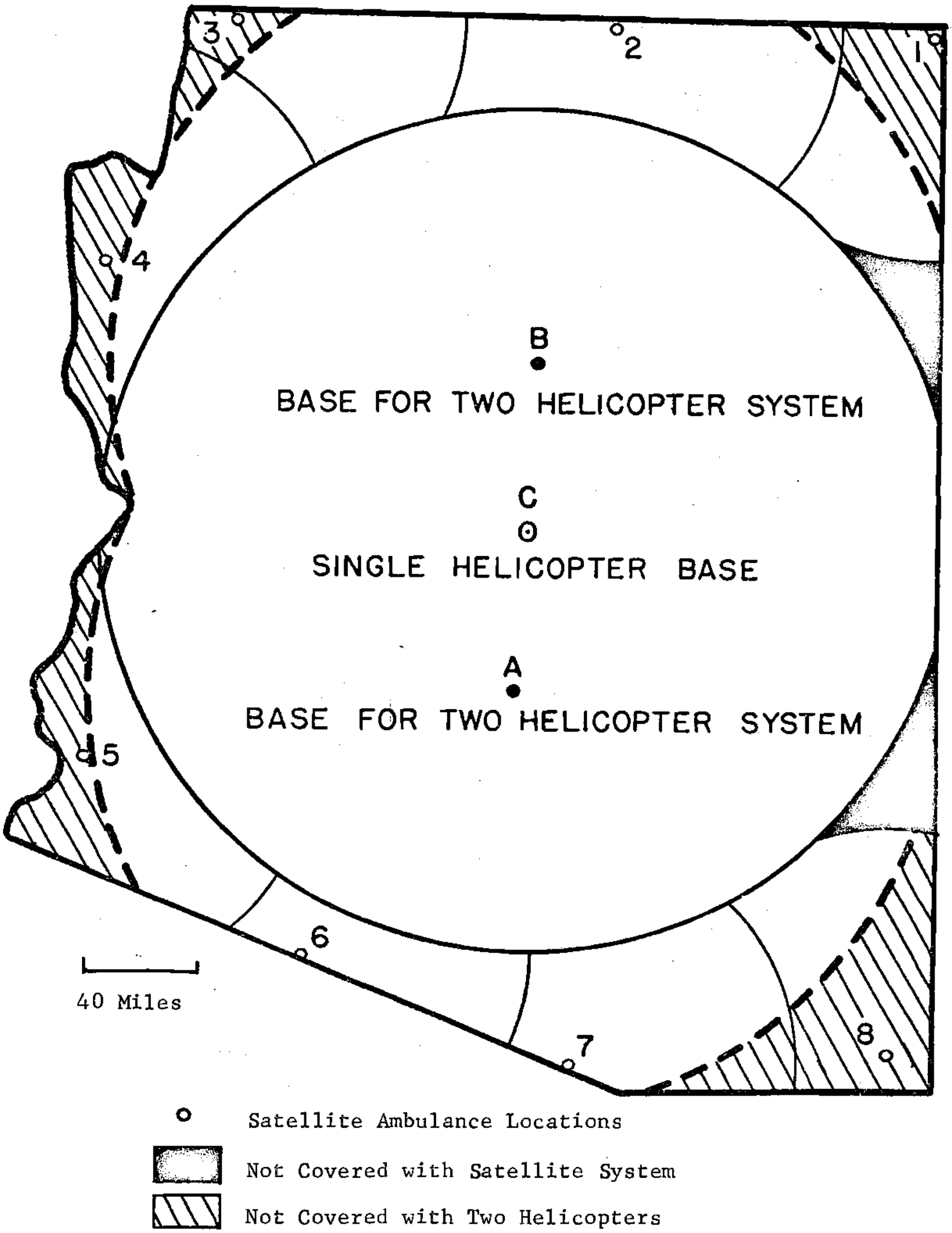


Figure 1. Comparative Coverage in Arizona--Two Helicopters or One Helicopter with Satellite Ambulances.

The two step method of evacuation indirectly suggests that satellite locations, or decentralization of ambulances requires more investigation. The City of New York utilized a computer simulation of its Kings County Hospital District in 1967. The objective of the simulation was to attempt to improve ambulance service by decreasing two related performance measures:

(1) response time - the period between receipt of a call at the ambulance station and arrival of an ambulance at the scene;

(2) round-trip time - the period between receipt of a call at the ambulance station and arrival of the assigned ambulance at the hospital with the patient.

Three alternatives were considered in the simulation. Two involved increasing the number of ambulances available and the third proposed redistributing the existing ambulances in the district by locating some of them at satellite garages.

It was found that emergency calls were not uniformly and randomly distributed throughout the area being studied. Due to varying population density and socio-economic characteristics certain subsections of the district had higher demands for ambulances than did others (13). This lack of randomness was also discovered in a study completed in the San Francisco area where it was discovered that Negro emergency patients, for instance, accounted for more than four times what would be expected if calls were based on Negro proportional representation in the urban population (10).

Figure 2 shows the clustering of calls found in the Kings County Hospital District. A superficial look at Figure 2 suggests that a

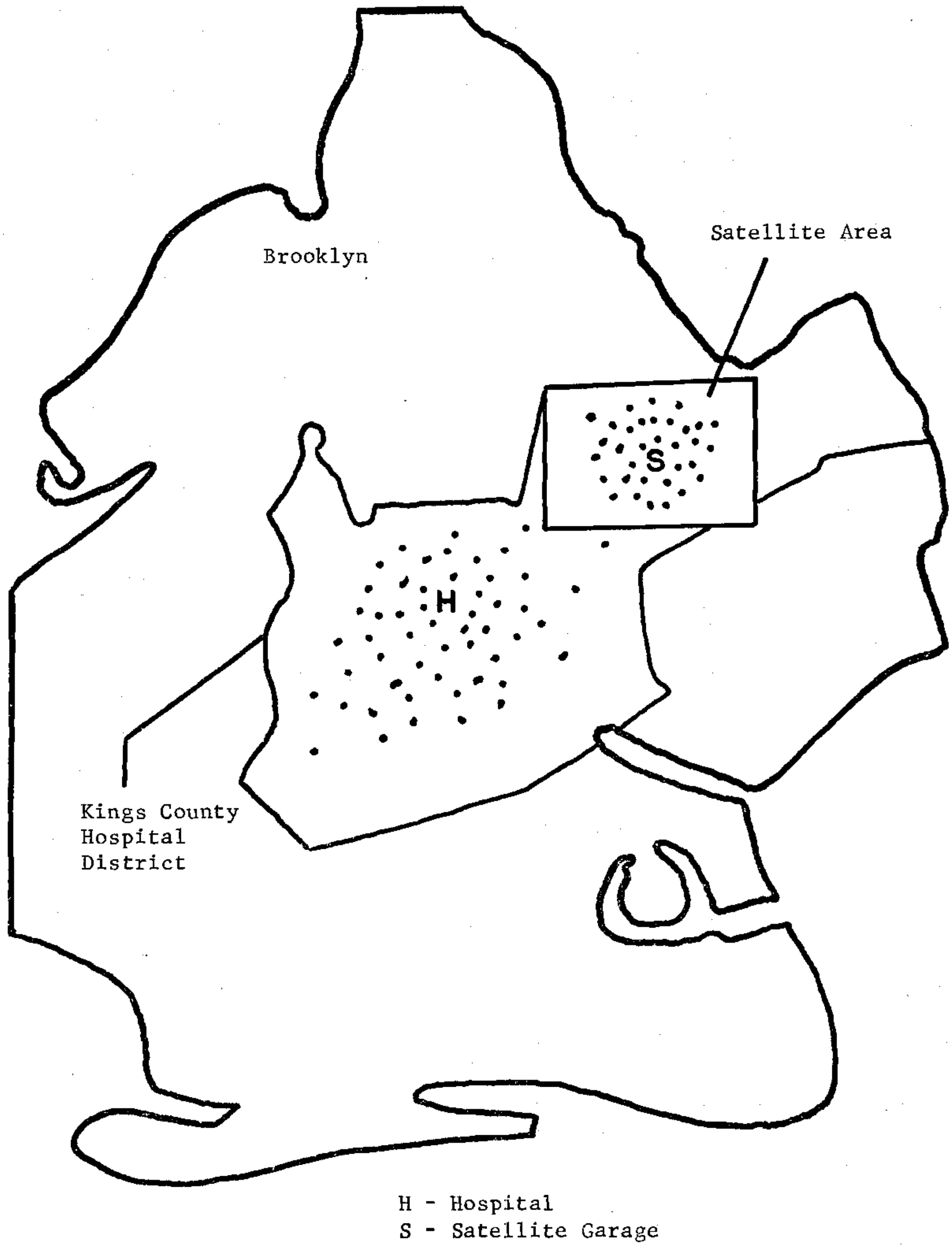


Figure 2. Ambulance Call Distribution in Kings County Hospital District.

substantial improvement in ambulance service could be achieved by stationing a satellite garage at point S. Since an ambulance located at S could pick up a patient and deliver him to the hospital while eliminating the trip from the hospital a 50 percent reduction in the time required to take a patient from the accident scene to the hospital was envisioned. The time for the ambulance to then return to the satellite garage was not considered.

During the simulation the number of ambulances available was held constant at seven. These were moved to the satellite location one by one. It was found that the greatest service time reduction was achieved when all seven ambulances were assigned to the satellite location. This finding was interpreted to mean that in this case a redrawing of hospital district lines was probably in order.

The second finding of interest in this simulation was that the time required to get a patient to the hospital was reduced by only five percent rather than the 50 percent envisioned.

Several explanations are given for these results. In the first place not all the time that elapses is travel time. As Figure 3 shows, various delays contribute to the total round-trip time and many of these cannot be eliminated by locating the ambulance elsewhere.

Secondly, the ambulances will be called upon to service from anywhere in the district, not only in the immediate vicinity of their satellite station. Finally, as the frequency of calls increases the ambulances will spend more and more time shuttling back and forth between the hospital and the satellite location.

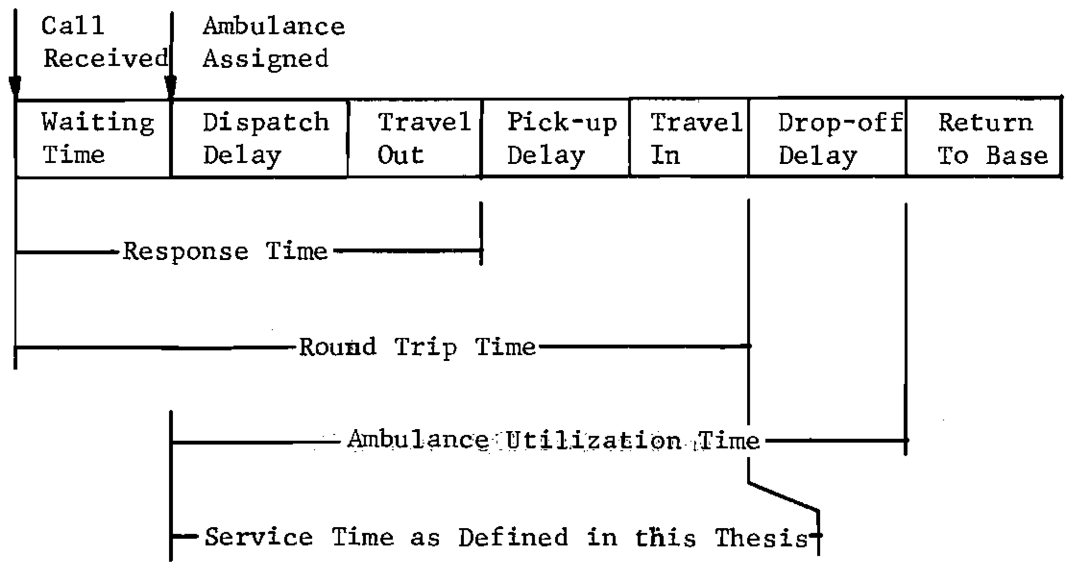


Figure 3. Sequence of Events During a Call Showing Time Relationships.

The final finding of interest was that as the number of ambulances available for service was increased, service time decreased to a certain point then leveled off, and then actually increased as is shown by Figure 4.

This may be attributed to the reduction in time needed to assign an ambulance to a call when more ambulances are available and less waiting time for a free ambulance is needed. The geographical characteristics of a district determine the actual travel time and a large number of ambulances will not reduce this time. Too many ambulances leads to a situation where they literally get in each other's way and response time may actually go up. This suggests an investigation of ambulance utilization.

Utilization may be defined as the fraction of the time that an ambulance spends on a call. The New York study determined that the minimum response time would be achieved when ambulance utilization was 42 percent. If the utilization figure was greater than this then improved service would result from the addition of more ambulances, and if less than 42 percent, ambulances could safely be released from the system.

If the number of ambulances is N and their utilization is U, then the number of ambulances, N', required in order to produce a utilization of 42 percent is given by the formula

$$N' = \frac{NU}{.42}$$

Among the conclusion of the New York studies (13) (16) were the following suggestions and recommendations.

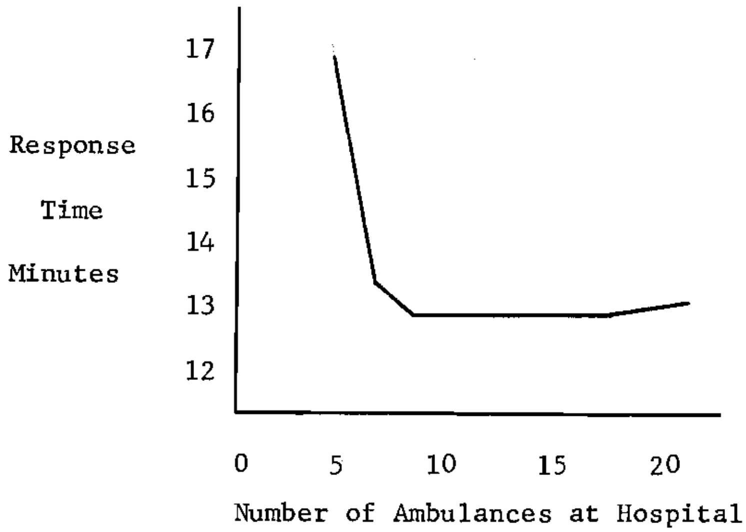


Figure 4. Response Times

(1) Ambulances ought to be stationed where the patients are. If the distribution of calls indicate that a particular hospital is well situated to serve as an ambulance station, it should be used as such.

(2) Ambulances should be completely dispersed. Rarely should there be two or more ambulances stationed at one location. In discussing satellite locations the studies not only suggested satellite garages, but on-the-street ambulance stations similar to bus stops, taxi stands, or reserved parking places in front of hotels. The latter suggestion would probably reduce the dispatching delay.

(3) A satellite station, without addition of ambulances to the currently existing fleet, is a relatively inexpensive way to improve ambulance response times because it places ambulances near the demand. The relative costs of three related alternatives is given in Table 1.

Cost effectiveness brings up the question of not only ambulance but helicopter costs. Though it is accepted that the helicopter is a much more expensive machine, it is often difficult to find agreement in actual dollar values given. It is also recognized that the operation of a helicopter ambulance would be more expensive than the operation of a vehicular ambulance systems now in use. Several things must be considered when the cost of either the helicopter or ground ambulance is examined.

Various figures for the hourly cost of operating a helicopter ambulance can be found. Operating costs for the Air Medical Evacuation Service Study were budgeted at $40 per hour although Fairchild Hiller promised $30 per hour costs. In its final report the AMES Study gave a figure of $45.69 as hourly operating costs (1). Using surplus H-19's

Table 1. Cost Comparison of Three Alternatives.

Alternative	Effectiveness Minutes Saved	Cost $/ Month	Cost Effectiveness $/Minute	Cost Per Call
Open a Satellite	1.5	2343	.43	.64
Add Three Ambulances	0.3	6286	5.73	1.72
Add Satellites and Ambulances	2.6	8629	.91	2.36

purchased from the Army for the Nebraska National Guard, cost per hour rises to $150. It must be remembered that the H-19 can accommodate eight to 10 stretchers, whereas the FH-1100 used in the AMES Study carried two patients (1, 8).

The operating costs of the Hughs 500 Executive Transport vary between $64.07 and $36.71 per hour dependent on the number of hours flown per year. Differences are found in indirect operating costs, primarily depreciation (7). Fairchild Hiller also states that the operating costs for the FH-1100 are $34.96 per hour, a fourth figure for one specific helicopter (4).

A direct comparison between ground and helicopter ambulance operating costs can be found in the operation of the Superior Ambulance Service of Detroit, Michigan. One common run for this service is from Wayne County General Hospital to the University of Michigan at Ann Arbor--a ground distance of 33 miles. Ground time is 40 minutes; helicopter time is 12 minutes. Patients are charged a flat fee of $30 per call plus $1.50 per mile for helicopter service as compared with $30 per call plus $1.00 per mile for ground ambulance service. The difference in cost is $16 for the run described while the difference in time is 28 minutes.

Superior estimates helicopter operating costs at $113.50 per hour, a much higher figure than was arrived at by the AMES Study. This may be explained by the wage differences for the two separate localities, different items being included in computation of operating costs, and the fact that the two different helicopter models are being compared. Surprisingly, Superior Ambulance Service uses a Bell 47J helicopter, a smaller and less expensive model than the Fairchild Hiller FH-1100. It is important to mention that Superior's helicopter operations are not making money at the rates charged. They do, however, provide experience and data (8).

Very quickly, we have established a relatively wide range of helicopter operating costs--from a low of $30 per hour to a high of $150 per hour. As a more detailed comparison of the costs of helicopter and ground ambulances is made, many more obstacles are encountered.

System set-up costs and operating costs must be determined to make a comparison between the two systems. System set-up costs include training, personal equipment, medical equipment, crew equipment, and communications. Operating costs include direct operating costs, fixed operating costs, and other associated fixed operating costs to include:

a. Personnel salaries;

b. Maintenance;

c. In service training; and,

d. Insurance.

Ground Ambulance Costs

Since ground ambulance costs are most commonly found, costs related to these systems will first be discussed in more detail. In a study conducted by the Gulf South Research Institute for the State of Louisiana (Project Number MS-221), it was pointed out that in a recently initiated emergency medical services program, the city of Jacksonville, Florida, had purchased completely equipped ambulances made up of a specially designed and constructed emergency medical care unit mounted on a one-ton truck chassis. The total cost for this ambulance was $12,500. The truck chassis which costs approximately $2800 will be replaced every three years, while the medical care unit, which accounts for most of the cost, will be used for at least nine years. Each unit meets the medical requirements for ambulance design and equipment, including radios (1).

The Jacksonville system becomes advantageous if the basic cost of the standard model ambulance is $7000 or more, and if it is replaced every three years. It is estimated that an ambulance currently costs $4000 in Atlanta (9). If these vehicles are replaced every three years, the total cost in nine years would be $12,000 as opposed to $20,900 for the Jacksonville system.

As ground ambulance systems are already in existence, their total set-up costs would be at best an estimate. A comparison of set-up costs between the helicopter and ground ambulance system will therefore not be made. There is also a wide range given for the actual cost of operating a system and three estimates of various costs are therefore provided (1, 16, 20).

Grady Memorial Hospital provided the operational costs of their ambulance service for 1968. These costs are shown in Table 2.

The study conducted by the City of New York, concerning the possible use of satellite locations for ambulances also provided costs for a ground ambulance service. These costs are shown in Table 3.

Using a report entitled, "The Economics of Highway Emergency Ambulance Services," by Dunlap and Associates and the Air Medical Evacuation System Demonstration Project, the final estimated capital and annual operating costs shown in Table 4 were arrived at (18).

Table 2. Grady Memorial Hospital Ambulance Service Operational Cost. (Six Ambulances and One Van)

Item	Cost/Year
12 Drivers Salaries	$63,800
Vehicle Supplies	100
Gasoline and Oil	5,500
Maintenance	4,000
	$74,400
12 Attendants Salaries	$40,320
Medical Supplies	1,000
	$41,320
Vehicle Liability Insurance	$ 2,700
Total Vehicle Operational Cost	118,420
Private Ambulance Emergency Backup	5,000
TOTAL COST	$123,420
Six Vehicles Total -- Five in use One in reserve One bus van	
Cost of Operating One Ambulance Per Year	$19,730
Cost of Operating All Ambulances Per Month	$1,644

Table 3. Analysis of Costs--New York Emergency Ambulance Service

Item	Purchase Price	Annual Cost	Total Annual Cost
I. Vehicle	$5,700	$950	$950[1]
Ambulance (6 yr. life)	4,900		
Equipment (6 yr. life)	800		
II. Vehicle Maintenance and Supplies		1,958	1,958
Maintenance and Repair Supplies		657	
Mechanic's Labor		505	
Gasoline and Oil		296	
Oxygen and Medical Supplies		500	
III. Ambulance Crew		14,505	72,525[2]
Motor-Vehicle Operator		8,175	
Salary		6,500	
Overhead (22%)		1,430	
Uniform Allowance		65	
Food Allowance		180	
Attendant		6,330	
Salary		5,000	
Overhead (22%)		1,100	
Uniform (issued)		50	
Food Allowance		180	
IV. Garage		13,600	13,600
Rent		12,000	
Heat		1,100	
Light		300	
Telephone		200	
V. Garage Staffing		14,516	14,516[3]
Foreman		9,395	
Salary		7,500	
Overhead (22%)		1,650	
Uniform		65	
Food Allowance		180	
Clerk		5,121	
Salary		4,050	
Overhead (22%)		891	
Food Allowance		180	

Table 3 Continued

[1]For three shifts per day, seven days per week.

[2]Allowing for vacations, illness, etc., five crews are required to staff an ambulance three shifts per day, seven days per week.

[3]Satellite operation is predicated on garage staffing for only eight hours per day, five days per week.

Table 4. Estimated Capital and Annual Operating Costs for Two Sizes of Emergency Ambulance Services

Cost Elements	22,000 Population Service Area 1 Location 2 Vehicles (840 calls/yr)	276,000 Population Service Area 2 Locations 6 Vehicles (10,050 calls/yr)
Fixed Cost Elements		
Driver/Attendant Wages	$60,230	$180,690
Support Personnel Wages	10,512	10,512
Employee Benefits (13.4%)	9,460	25,300
Vehicle Depreciation	1,866	4,698
Equipment Depreciation	2,156	6,468
Facilities Rental	7,580	18,440
Facilities Maintenance (30% of Rent)	2,274	5,532
Utilities (25% of Rent)	1,895	4,610
Telephone ($988 per manned ambulance)	1,976	5,028
Vehicle Insurance		
Basic Liability (20,000) $145/yr/vehicle	290	870
Excess Limits Liability (500,000) $465/yr/veh.	930	2,790
Business Insurance (est. as 17% of veh. ins. Incl. general, fire, contents, equipment damage)	207	622
Other fixed costs (1,500 per year per vehicle)	3,000	9,000
TOTAL FIXED COSTS	102,376	274,560
Variable Cost Elements		
Vehicle Operation and Maintenance ($3.25/call)	2,730	32,662
Other Variable Costs ($2.25/call)	1,890	22,613
TOTAL VARIABLE COSTS	4,620	55,275
TOTAL ANNUAL COST	$106,996	$329,835

A comparison of the three tables of ambulance operating costs is difficult because each takes different items into account, and each is based on a different section of the country. Using Grady Hospital's data as a base, however, the following comparison can be arrived at.

Grady Hospital gives the cost of operating an ambulance for one year as \$19,730. Removing the proportionate cost of insurance for one vehicle, \$450, we arrive at an adjusted figure of \$19,280. Using only those costs included in this figure to calculate the operating cost of one ambulance for one year in New York we obtain the following figures.

Maintenance and Repair Supplies	\$657
Gasoline and Oil	296
Oxygen and Medical Supplies	500
Motor Vehicle Operator Salary	13,000
Attendant Salary	10,000

The total cost in the New York system adjusted to include only those items common to both Grady and New York is \$24,453.

Extending the comparison to Table 4, we arrive at a figure of \$35,559 per ambulance per year. This great disparity can be explained by more closely examining salaries. First of all, Atlanta pays much lower than average labor rates for drivers and attendants than does the rest of the nation (20). When compared to Atlanta, the higher operating cost shown for New York emergency ambulance services is almost totally attributable to the difference in wages being paid to both the attendant and the driver.

In addition, the figure arrived at by using Table 4 is based on the attendant having the same training as a medical corpsman, and the driver being at an intermediate training level demanding a higher wage. If minimum standards are used for both driver and attendant qualifications, the cost of driver/attendant wages per vehicle can be adjusted down from $30,115 to $19,324. Adding to this, the vehicle operation and maintenance costs, we arrive at a figure of $24,768.

Even when comparing costs of established systems, we do not easily find complete agreement. As has already been mentioned, helicopter operating costs can quickly be given a wide range of values. The most detailed analysis of costs associated with the helicopter ambulance is provided by the AMES Study. Using the ground ambulance already compared, we can easily conclude that helicopter operating costs will be at least, if not more, variable between different localities.

Helicopter Ambulance Costs

As with ground ambulances, the most comprehensive figures for the costs associated with the helicopter ambulance may be found in the Air Medical Evacuation System Final Report. These costs, including set-up and operating costs, are summarized in Table 5.

As could be expected, the cost of operating a helicopter ambulance is much more than that of operating a motor ambulance. Only a major reduction in the time needed to take a patient from his present location to a medical facility would justify the use of the helicopter when considering only cost effectiveness. Even then the value of a human life, impossible to precisely define, must be considered.

Table 5. Helicopter Ambulance--Associated Costs

Item	Cost
Set-Up Costs	
Purchase Price FH-1100 Helicopter with Aircraft Accessories[1]	$116,442.50
Helicopter Medical Equipment	794.37
Helicopter Crew Equipment	6.85
Control Hospital Radio Communications-Equipment and Installation	1,481.00
Medical Training Set-Up Costs[2]	10,644.05
Personal Equipment	1,620.52
Hospital Heliport[3]	2,000.00
TOTAL SET-UP COSTS	$132,989.29
Monthly Fixed Costs	
Insurance	$ 2,026.17
Depreciation of Helicopter	1,940.71
Pilot's Salaries and Payroll Costs (5 pilots)	8,685.00
Mechanic's Salary and Payroll Costs	1,014.00
Paramedics Salaries and Payroll Costs (5 Paramedics)	4,650.00
Supervisor's Salary and Payroll Costs	1,125.92
TOTAL MONTHLY FIXED COSTS	$ 19,441.80
Helicopter Direct Operating Costs[4] $45.69/Hour x 150 Hours/Month	$ 6,854.00
TOTAL MONTHLY COSTS	$ 26,295.80

[1] The cost of a snow kit included in the AMES Report was deleted to obtain the cost shown.

[2] For five crews and one supervisor. A crew consists of a pilot and paramedic. (See Note 2, Table 3.) Cost includes salaries, payroll costs, expendable supplies, on-the-job training, and the American Academy of Orthopedic Surgeons Training Course.

[3] A survey by the Vertical Lift Council found that hospital heliports in existence ranged in cost from $100 to $40,000. Costs between $1000 and $3000 were most typical, however, and $2000 represents an average of

Table 5 Continued

these typical costs (6).

[4]Includes fuel, oil, scheduled and unscheduled maintenance and parts, reserve for parts, and radio maintenance and parts.

The major cost in the helicopter ambulance system is that of the helicopter itself. It has been suggested that when hostilities cease in Vietnam, a large number of helicopters will be declared surplus and made available to public agencies at very low prices. In addition, the military experience is expected to provide a large number of men who have served as paramedics and thus have experience in helicopter evacuation. Both of these predictions could substantially reduce helicopter ambulance set-up costs (8).

The cost of operating any ambulance service has continually increased and may cause a major change in the service. Funeral homes provide a large number of the ambulances available in the southern states, and three-fourths of these reported operating at a loss. Thus economics are already forcing the funeral home out of the ambulance business. Add new standards for ambulance, driver, and attendant and we find that many more ambulance services will be forced to stop operations (17, 18).

Meanwhile, to be eligible for federal aid for highways, a state must insure that emergency medical care and transportation of the injured will be provided (18). A solution is state and local governmental control and subsidizing of emergency services. Once the ambulance is viewed as a necessary public service, operating funds for the helicopter ambulance may become available.

Even when this becomes the case, however, a system which will minimize the number of helicopters needed to provide a quickly responsive service, and the trade-off of several ambulances for one helicopter must be kept in mind.

CHAPTER II

DATA COLLECTION FOR THE MODEL

General Discussion

To simulate the systems proposed, statistical data related to several facets of the ambulance system were collected and evaluated. The data that was required for this study could not be obtained from a single source. Nevertheless, most of the information required was obtained by observation, historical records, and interviews with the personnel of Grady Memorial Hospital ambulance system.

Those areas for which data was collected for inclusion in the computer simulation include the following:

(1) Call arrival rate.

(2) Distance from the hospital or satellite location to the patient, or patient location.

(3) Weather conditions effecting helicopter operations.

(4) Speed of the ambulance.

(5) Delay of ambulance at patient scene.

(6) Delay of ambulance when leaving the hospital.

(7) Delay after returning to the hospital and before returning to service.

(8) False calls and calls not needing actual evacuation by ambulance.

Call Arrival Rate

The distribution of time between ambulance calls taken from hospital records closely approximated a negative exponential distribution as shown in Figure 5. Wilmot (19) found that the negative exponential also described the distribution of time between accident calls. As a result, the negative exponential was used in the model to determine ambulance call times.

Distance to Patient

Two studies were found which examined the distribution of the distance from the hospital to an accident or patient scene. Wilmot (19) assumed that the distance from the hospital to the scene of an accident conformed to a negative exponential with a mean of three miles. Using a sample size of 22, Blum (2) proposed that the distance was normally distributed with a mean of 3.82 miles. A report by Grady Hospital, though giving no distribution, found the average distance an ambulance traveled to the scene of a call was 3.8 miles (9).

In that a decentralized system of ambulances is being studied and distance is therefore of extreme importance, a random sample of 539 calls was used to obtain a distribution, and later to assign satellite locations. These calls were plotted on a map of Atlanta and are shown in Figure 6.

The distance between Grady Hospital and each patient site was then calculated in the following manner. A set of x,y, coordinates in tenths of a mile was given for each patient site or call and for Grady Hospital. Since vehicles usually cannot travel in a straight

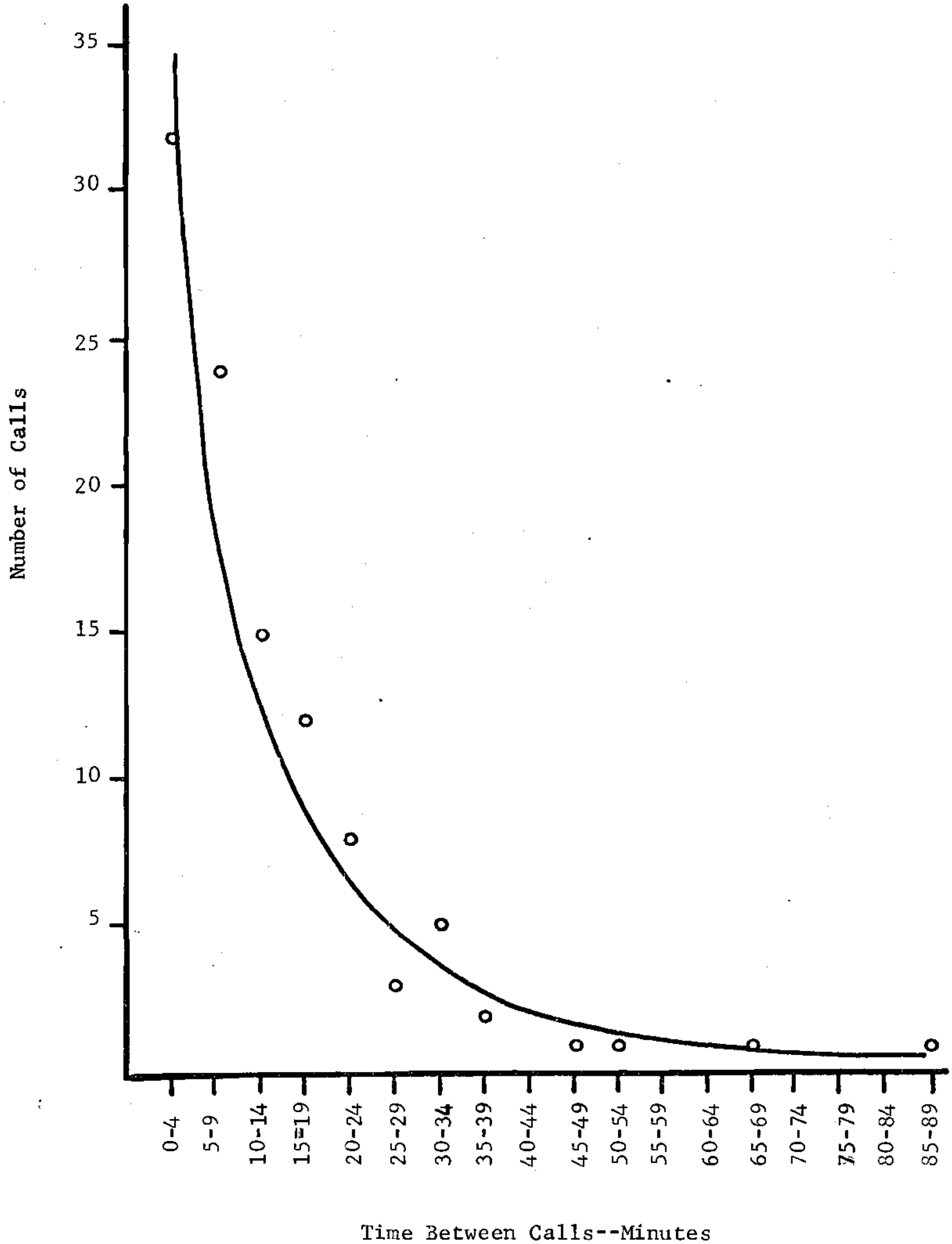
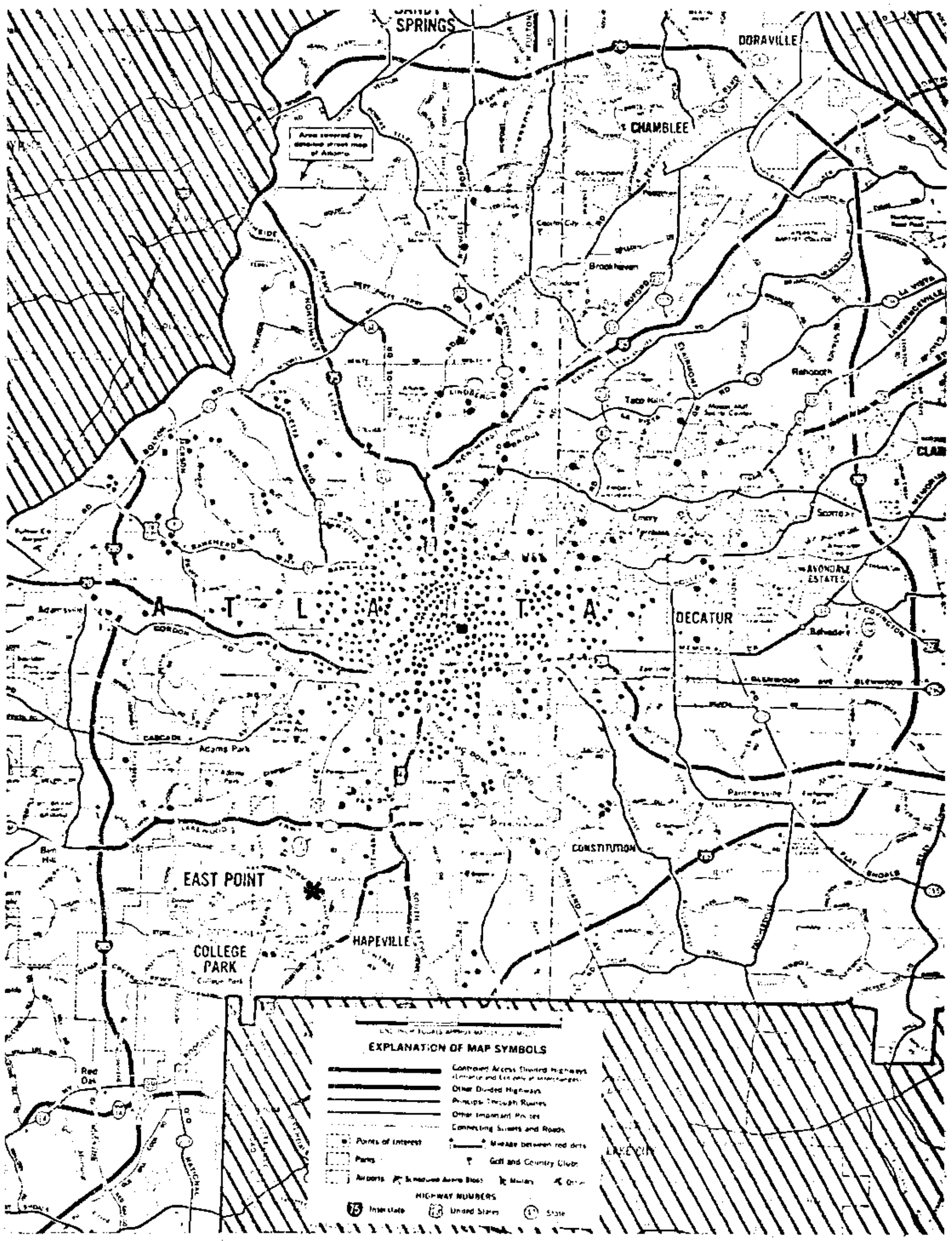


Figure 5. Time Between Calls



■ Grady Memorial Hospital

✱ South Fulton Hospital

Figure 6. Call Distribution.

line between points, travel distance was estimated using a metropolitan or rectangular measure in which the travel distance between the two points a and b is

$$\left| X_a - X_b \right| + \left| Y_a - Y_b \right| \tag{11}$$

Using this system, Figure 7 was obtained.

The average distance to a patient was found to be 3.1 miles. The histogram shown in Figure 7 is quite reasonable. A large number of calls extremely close to the hospital would not be expected as ambulance evacuation because of the short distances involved. As we get further and further away from the hospital, the number of requests again goes down as local ambulance services, and not the central system at Grady, are being used.

To more accurately represent the true state of affairs for the total call population, the data distance distribution was adjusted or smoothed. The resulting hypothetical distribution of call distances is shown in Figure 8, and this distribution will be used in the simulation.

To test the donformity of the hypothetical distance distribution to the data distribution, the Kolmogorov-Smirnov goodness of fit test was used based on the data contained in Table 6. This test concerns itself with the largest single deviation between the data and the hypothesized cumulative distribution (14). The acceptable deviation is given by

$$L \sqrt{\frac{N_1 + N_2}{N_1 N_2}} \tag{15}$$

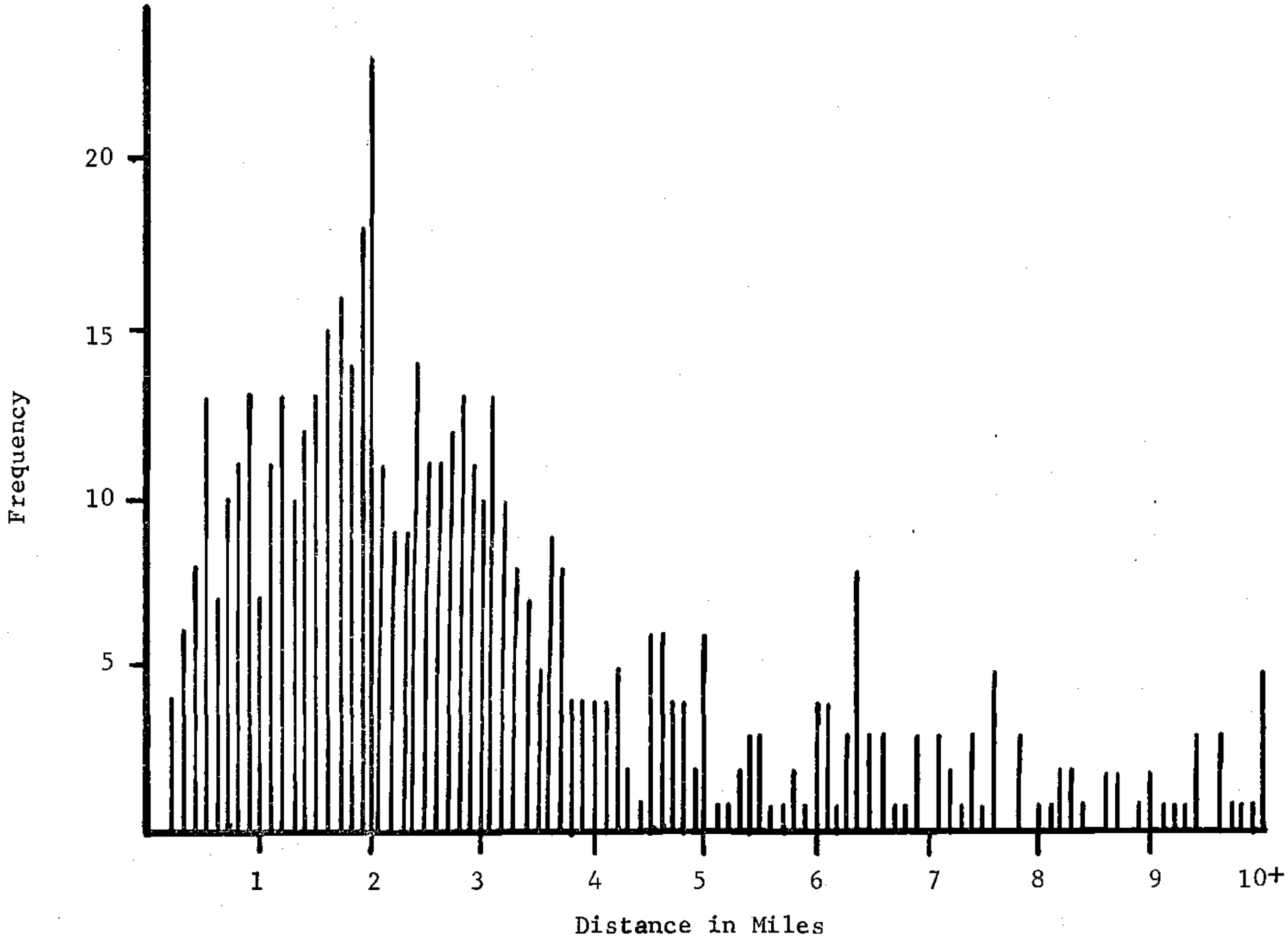


Figure 7. Distribution of Call Distance From Data.

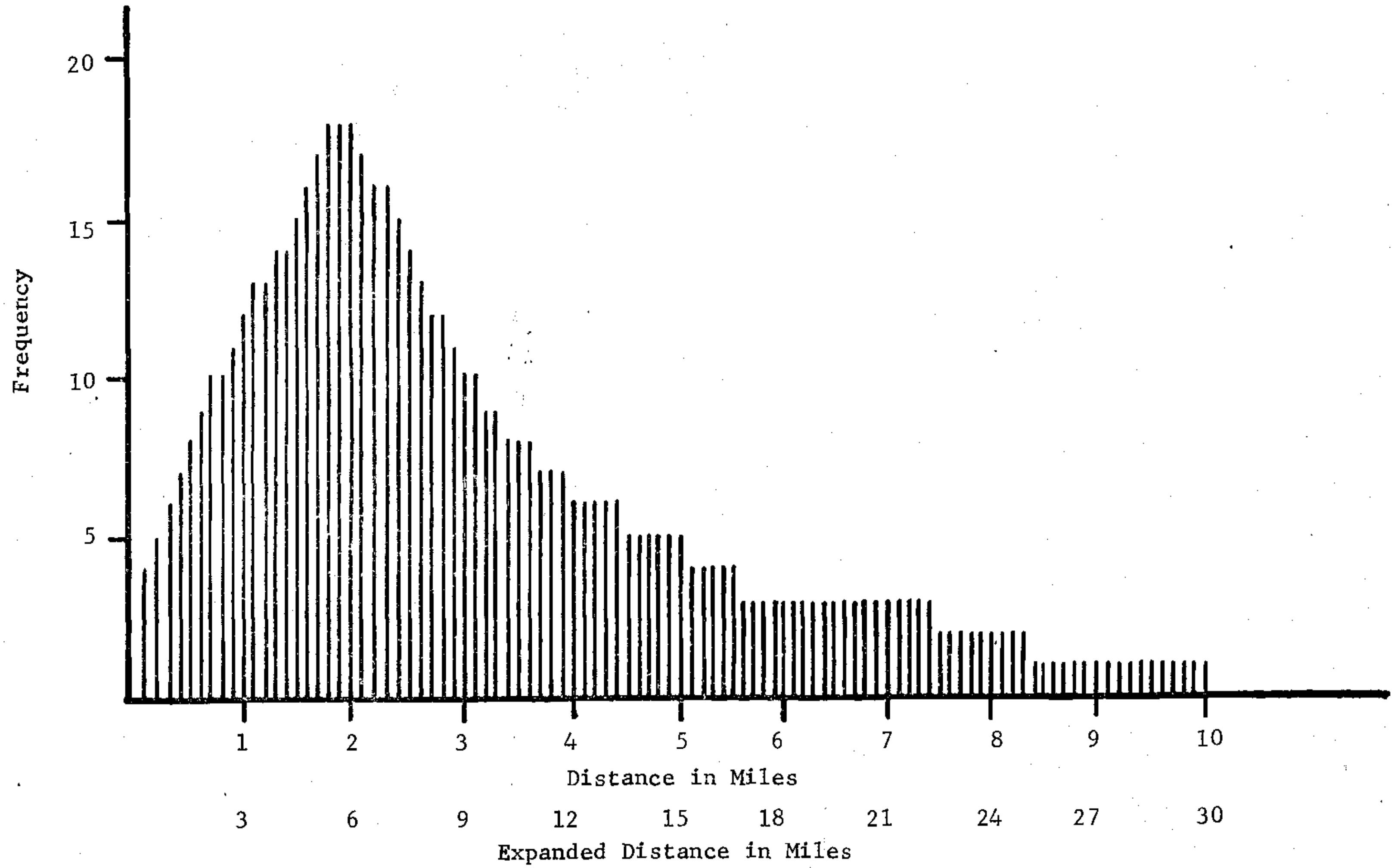


Figure 8. Distribution of Call Distance Hypothesized.

Table 6. Distribution of Call Distance

Distance (Miles)	Hospital Data Frequency	Hospital Data Cumulative Distribution	Hypothetical Data Frequency	Hypothetical Data Cumulative Distribution	Difference Between Cumulative Distribution
0.1	0	.000	4	.007	.007
0.2	4	.007	5	.015	.008
0.3	6	.019	6	.024	.006
0.4	8	.033	7	.036	.003
0.5	13	.058	8	.049	.009
0.6	7	.071	9	.063	.008
0.7	10	.089	10	.080	.009
0.8	11	.109	10	.096	.013
0.9	13	.134	11	.114	.020
1.0	7	.147	12	.133	.014
1.1	11	.167	13	.154	.013
1.2	13	.191	13	.175	.016
1.3	10	.210	14	.198	.012
1.4	12	.232	14	.221	.011
1.5	13	.256	15	.245	.011
1.6	15	.284	16	.271	.013
1.7	16	.314	17	.299	.015
1.8	14	.340	18	.328	.012
1.9	18	.373	18	.357	.016
2.0	23	.416	18	.386	.030
2.1	11	.436	17	.414	.022
2.2	9	.453	16	.440	.013
2.3	9	.469	16	.466	.003
2.4	14	.495	15	.490	.005
2.5	6	.506	14	.513	.007
2.6	12	.529	13	.534	.005
2.7	13	.553	12	.554	.001
2.8	14	.579	12	.573	.006
2.9	11	.599	11	.591	.008
3.0	10	.618	10	.607	.011
3.1	13	.642	10	.623	.019
3.2	10	.661	9	.638	.023
3.3	8	.675	9	.653	.022
3.4	7	.688	8	.666	.022
3.5	5	.698	8	.679	.019
3.6	9	.714	8	.692	.022
3.7	8	.729	7	.703	.026
3.8	4	.737	7	.714	.023
3.9	4	.744	7	.726	.018
4.0	4	.751	6	.735	.016
4.1	4	.759	6	.745	.014

Table 6 Continued

Distance (Miles)	Hospital Data Frequency	Hospital Data Cumulative Distribution	Hypothetical Data Frequency	Hypothetical Data Cumulative Distribution	Difference Between Cumulative Distribution
4 4.2	5	.768	6	.755	.013
4.3	2	.772	6	.765	.007
4.4	1	.774	6	.774	.000
4.5	6	.785	5	.782	.003
4.6	6	.796	5	.791	.005
4.7	4	.803	5	.799	.004
4.8	4	.811	5	.807	.004
4.9	2	.814	5	.815	.001
5.0	6	.826	5	.823	.003
5.1	1	.827	4	.830	.003
5.2	1	.829	4	.836	.007
5.3	2	.833	4	.843	.010
5.4	3	.839	4	.849	.010
5.5	3	.844	4	.856	.012
5.6	1	.846	33	.860	.014
5.7	1	.848	3	.865	.023
5.8	2	.851	3	.870	.019
5.9	1	.853	3	.877	.024
6.0	4	.861	3	.880	.019
6.1	4	.868	3	.885	.017
6.2	1	.870	3	.890	.020
6.3	3	.876	3	.895	.019
6.4	8	.891	3	.899	.008
6.5	3	.896	3	.904	.008
6.6	3	.902	3	.909	.007
6.7	1	.904	3	.914	.010
6.8	1	.905	3	.919	.014
6.9	3	.911	3	.924	.013
7.0	0	.911	3	.929	.018
7.1	3	.917	3	.933	.016
7.2	2	.920	2	.937	.017
7.3	1	.922	2	.940	.018
7.4	3	.928	2	.943	.015
7.5	1	.930	2	.946	.016
7.6	5	.939	2	.950	.011
7.7	0	.939	2	.953	.014
7.8	3	.944	2	.956	.012
7.9	0	.944	2	.959	.015
8.0	1	.946	2	.963	.017
8.1	1	.948	2	.966	.018
8.2	2	.952	2	.969	.017
8.3	2	.956	2	.972	.016
8.4	1	.957	1	.974	.017
8					

Table 6 Continued

Distance (Miles)	Hospital Data Frequency	Hospital Data Cumulative Distribution	Hypothetical Data Frequency	Hypothetical Data Cumulative Distribution	Difference Between Cumulative Distribution
8.5	0	.957	1	.976	.019
8.6	2	.961	1	.977	.016
8.7	2	.965	1	.979	.014
8.8	0	.965	1	.981	.016
8.9	1	.967	1	.982	.015
9.0	2	.970	1	.984	.014
9.1	1	.972	1	.985	.013
9.2	1	.974	1	.987	.013
9.3	1	.976	1	.989	.013
9.4	3	.982	1	.990	.008
9.5	0	.982	1	.992	.010
9.6	3	.987	1	.994	.007
9.7	1	.989	1	.995	.006
9.8	1	.991	1	.997	.008
9.9	0	.991	1	.998	.007
10.0	-	-	1	1.000	.000
10 +	5	1.000	-	-	-

where L is the significance level factor and N_1 and N_2 are the number of elements in the two samples on which the distributions are based.

In this case the acceptable deviation was determined to be

$$1.36 \sqrt{\frac{1155}{(539)616}} = .0802$$

for a significance level of 0.05.

Since the maximum deviation found was .030 at 2.0 miles, the hypothesis of conformity cannot be rejected.

Further analysis of the Grady data indicates that only 0.9 percent of the calls received are from a distance of 10 miles or greater. To provide an area of sufficient size to warrant the use of the helicopter ambulance, all call distances were multiplied by three, and the new scale is also indicated in Figure 8.

False Calls and Calls Not Needing Evacuation

Figure 6 also indicates that Grady Memorial Hospital is probably very well situated to serve the community. In general, the inner-city, downtown hospital, will be in an area of a highddistribution of calls. Data collected at Grady Memorial Hospital and the report by Blum (2) indicated that Grady's ambulance service is primarily used by low-income, black, and inner city residents although it is available to, and does serve outlying areas and their residents equally well. The grouping of people primarily served by Grady ambulances is not unique in Atlanta as was previously mentioned in discussing the New York and San Francisco studies.

Although not all calls received by Grady are true emergencies, each is significant in that it decreases the number of ambulances available for emergency service. One patient called the ambulance only after she grew tired of waiting for a taxicab. This may be attributable to the fact that certain individuals below a prescribed income level are provided with "Grady Eligible Cards" allowing them to receive medical attention without cost. This attention includes ambulance service (9).

In the San Francisco study (10), it was found that not less than nine percent of the patients were either gone when the ambulance arrived or refused service. These two situations will be defined as false calls. Three percent of all calls received were given emergency care, guidance, and reassurance but no further treatment and were not transported. These figures are important in that an ambulance becomes available for further service when it arrives at a scene and finds no patient present or only delays long enough to render on-the-spot assistance to the caller.

For this simulation, it will be assumed that nine percent of nonhelicopter calls will be false calls, and three percent of nonhelicopter calls will require aid but not transportation.

Delay of Ambulance at Patient Scene

When an ambulance arrives at the scene from which a call was received some delay is inevitable if a patient is present. Simply loading the individual into the ambulance requires a certain amount of time, and if first aid is necessary this time increases.

If the call is false, a zero delay will be assumed. In the

San Francisco study (10), those calls in which the patient required only on-the-spot attention found 67 percent requiring 15 minutes or more; in 25 percent five minutes; and in eight percent less than four minutes. Sample size was 252. Those calls requiring actual transportation from the scene found 40 percent requiring 15 minutes or more; 30 percent five minutes; and the remaining 30 percent less than four minutes. Sample size in this case was 3106.

Blum (2) using a sample size of 22 found the time elapsed at the call scene when transportation was required to be normally distributed with a mean of 3.12 minutes, standard deviation of 2,39 minutes, and range of 2.06 to 4.18 minutes.

Because of the apparent disagreement between the two sets of data, more reliance was placed in the San Francisco study because of the difference in sample size. The minimum delay found in the Blum paper, approximately two minutes, will also be used.

For this simulation delay at the scene not requiring transportation will be provided by a function assigning 67 percent of the calls a delay of between 15 and 20 minutes, 25 percent a delay of five minutes, and eight percent a delay of between four and two minutes. If transportation is required, 40 percent of the calls will be assigned a delay of between 15 and 20 minutes, 30 percent a delay of five minutes, and the remaining 30 percent a delay of between four and two minutes.

Speed of the Ambulance

Blum (2) also provides an ambulance speed distribution in his paper. Average speed of an ambulance both going to and returning with a patient was found to be normally distributed with a mean of 26.65 miles per hour and a standard deviation of 12.57 miles per hour. Though this figure is considerably less than the 50 miles per hour speed assumed in the AMES Report (1), it should be remembered that the Grady ambulances operate in a much more congested area.

Average speed for calls may also present a misleading picture. An emergency run with an average speed of 15.1 miles per hour actually reached a top speed of 70 miles per hour during the run. The actual range of average speeds on individual runs was found to be 7.7 to 58.2 miles per hour.

In this simulation, the normal distribution Blum arrived at will be used to determine the speed of an ambulance within 10.8 miles of the hospital. Beyond that distance, it will be assumed that congestion decreases and a 50 mile per hour speed is again reasonable.

Delay After Returning to the Hospital

Even after the ambulance has physically reached the hospital with the patient, it is not immediately available to answer another call. Such routine actions as refueling require a certain amount of time. The condition of the patient will vary and with it the delay associated with that patient. In the extreme case of a patient who dies enroute to the hospital, the maximum delay occurs in the Grady system. A doctor must pronounce the patient dead, the ambulance must then take the patient to the morgue, and attendants are required to remain present while personal effects are inventoried. This delay has been known to take up to an hour (9).

In evaluating the delay experienced at Grady Memorial Hospital, the curve shown in Figure 9 was obtained. The curve conforms to a negative exponential and will be used for this simulation.

Delay of Ambulance When Leaving the Hospital

When a call for an ambulance reaches a hospital, there is some delay before the ambulance actually leaves to answer the call. Time is required for the ambulance crew to get from their waiting area to the ambulance itself. Next the vehicle must be started and the actual departure made. Traffic, both pedestrian and vehicular, may again delay this departure.

Statistical data for these two delays are provided in the Blum paper (2). Through direct observation and stopwatch measurements at Grady Memorial Hospital, the figures shown in Table 7 were arrived at.

A constant value of one minute will be used in the model to simulate the delay of an ambulance in leaving the hospital.

Weather Conditions Affecting Helicopter Operations

In the simulation model proposed by Wilmot (19), a weather section is provided. The weather conditions for a particular time are determined from probability functions for each of the twelve months. Data for these functions was obtained from the metropolitan weather summaries published by the United States Weather Bureau. It was assumed that a helicopter ambulance could not be used in weather conditions providing less than 0.5 miles visibility and 500 feet of ceiling.

A two step system of helicopter evacuation provides the

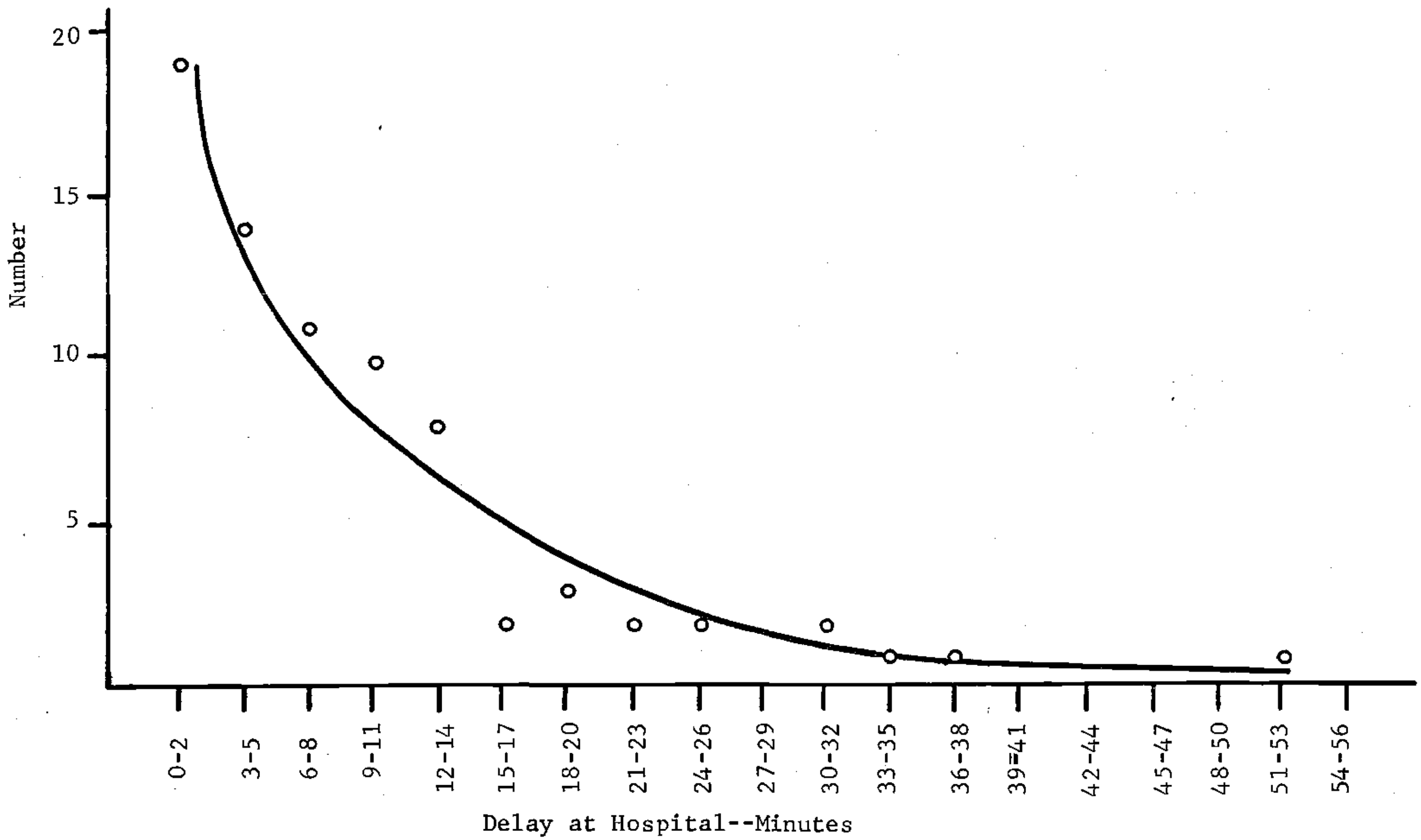


Figure 9. Delay After Reaching Hospital and Before Returning to Service.

Table 7. Dispatch Delay

	Computed Data		Observed Data	
	Mean	Standard Deviation	Lower Limit	Upper Limit
Time required to reach a vehicle (minutes)	.43	.47	.25	.62
Time required to leave hospital area (minutes)	.66	.94	.30	1.03

possibility of using the helicopter ambulance even under instrument flight conditions as was previously discussed. Assuming this possibility exists will further provide the best possible case for two step evacuation, and will be assumed in this simulation model.

Other Delays

In addition to those operations for which statistical data was analyzed to arrive at a waiting period or delay, several other areas must be considered. In general, these other delays will be assumed to be constant and most are related to helicopter ambulance operations for which statistical data is not available.

Maintenance

Aircraft maintenance will be simulated quite simply. Each time the helicopter has accumulated 100 flying hours, it will be removed from the system for periodic maintenance. It will be returned to service after 48 hours have elapsed.

Since four vehicles are kept in reserve for the ground ambulance system from which the majority of data was obtained, no provision for simulation of ambulance maintenance will be made.

Delay of Helicopter Leaving Hospital

As with the ground ambulance, the helicopter will not leave the exact instant that a call for service is received. The crew must board and start the aircraft, and then must perform several navigational and engine instrument checks. These operations will be assumed to take six minutes and will further assume that all other preflight checks will be accomplished during periods in which the helicopter is not being used.(1).

Delay of Helicopter at Pick-Up Site

The helicopter delay at pick-up site will involve only that time required to transfer a patient from the ambulance to the helicopter and to exchange any essential information about the patient between attendants. Any immediate assistance needed by the patient will have already have rendered by the ambulance crew. It will be assumed that the transfer will remain constant at five minutes.

Delay in Returning Helicopter to Service

When the helicopter returns to the hospital, it may be assumed that delivery of the patient to the proper clinic will be accomplished by other means. Delay will be less than the ambulance, may involve refueling and clean up, and will be assumed to remain constant at 15 minutes.

Helicopter Speed

The speed of the helicopter ambulance will be assumed to be constant at 90 miles per hour.

Grid Coordinate System

Although a distribution providing the distance from the central ambulance facility has been obtained, some manner of dealing with satellite ambulances and helipads is needed.

If calls received, ambulance locations, and helipads are assigned a set of x,y, coordinates several problems encountered in using only the distance distribution are eliminated. Sector assignments can be simplified by assigning certain coordinate groupings to a particular designated area. A program can then be written which will calculate the distance between an ambulance and a call, and the call and the hospital, using the rectangular measure system. Distance between the satellite location and the hospital will of course remain constant. Since the helicopter will fly in a straight line, this slightly different computation is also possible.

To generalize the model, the adjusted distances generated will be assigned coordinates in a 60 by 60 mile grid coordinate system with the hospital assumed to be at the center. Initially, six ambulances will be retained and will be assigned positions based on smoothed distance distribution and appropriate adjustments of the coordinates obtained from the plotted data shown in Figure 6.

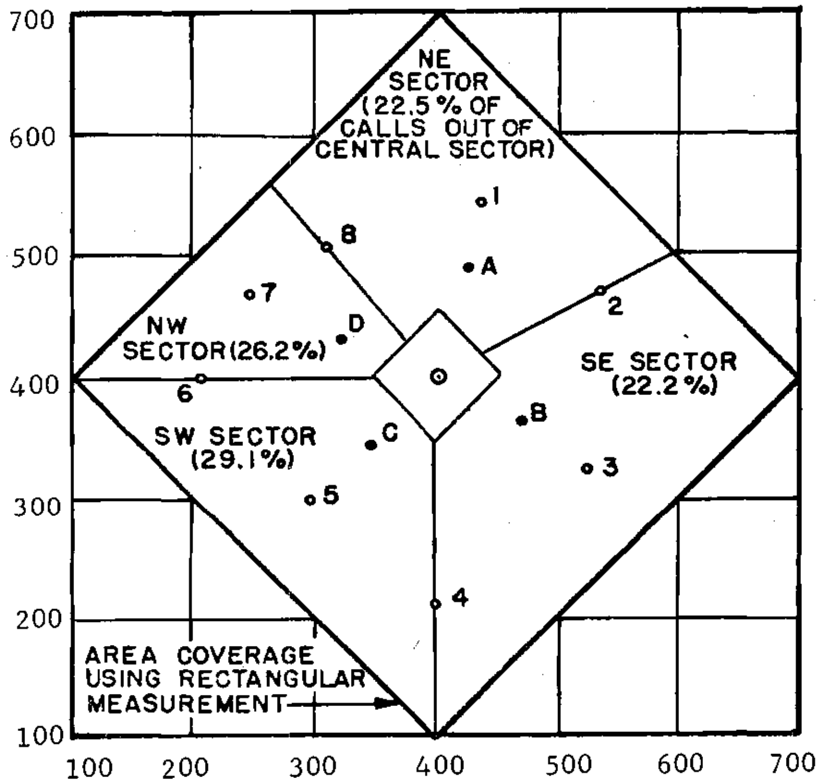
Two ambulances will remain at the hospital with first priority for all calls received from distances of 5.4 miles or less. This will account for 32.8 percent of approximately one third of all expected calls.

Remaining calls will be distributed among four satellite sectors each assigned one ambulance. Satellite sectors will be drawn such that each receives an approximately equal number of calls, causing sectors to be of different size and shape. Satellite ambulances will be located 10.8 miles from the central hospital and approximately centered in their sector.

In phase three, calls received from a distance of greater than 10.8 miles from the hospital will use helicopter evacuation. For this purpose, satellite helipads will be located in each of the outer sectors. Eight helipads will be assumed. One helipad in each sector and one each on the boundary between sectors will provide each sector a choice of three helipads. It is also assumed that helipads will be available without cost. For example, the parking lot of a shopping center could be used.

Figure 10 is a diagram of the proposed system and includes percentages of calls in each sector, locations of helipads and satellite locations, and sector boundaries. The shape of the actual area covered is a result of the rectangular system of measurement being used.

For simulation purposes, the percentageoôf calls at a given distance in each sector outside the central sector is provided in Table 8. For those values that were not found in the statistical data, an example being 21.0 miles, it was assumed that an equal number of calls would be received from each sector.



10 Miles

⊙ Central Hospital

• Satellite Ambulances

Location	Coordinates
A (NE)	418490
B (SE)	466358
C (SW)	346346
D (NW)	325433

∘ Satellite Helipads

Location	Coordinates
1 (NE)	434569
2 (NE/SE)	536468
3 (SE)	526321
4 (SE/SW)	400196
5 (SW)	298299
6 (SW/NW)	196397
7 (NW)	326434
8 (NW/NE)	305510

Figure 10. Sector Assignment of Calls

Table 8. Call Distribution by Sector

Adjusted Distance	Total Calls	NE Sector #	NE Sector %	NW Sector #	NW Sector %	SE Sector #	SE Sector %	SW Sector #	SW Sector %
5.7	18	4	.222	4	.222	7	.167	3	.389
6.0	23	6	.261	4	.174	3	.130	10	.435
6.3	11	3	.273	1	.091	3	.273	4	.363
6.6	9	3	.333	2	.222	1	.112	3	.333
6.9	99	2	.222	2	.444	2	.222	1	.112
7.2	14	3	.214	4	.286	2	.143	5	.537
7.5	6	1	.167	3	.500	2	.333	0	.000
7.8	12	4	.334	1	.083	1	.083	6	.500
8.1	13	2	.154	5	.384	4	.308	2	.154
8.4	14	1	.072	4	.286	3	.214	6	.428
8.7	11	3	.273	3	.273	1	.091	4	.363
9.0	10	0	.000	3	.300	4	.400	3	.300
9.3	13	2	.154	3	.230	4	.308	4	.308
9.6	10	1	.100	2	.200	3	.300	4	.400
9.9	8	1	.125	0	.000	3	.375	4	.500
10.2	7	2	.268	0	.000	4	.571	1	.143
10.5	5	1	.200	2	.400	2	.400	0	.000
10.8	9	2	.222	1	.112	3	.333	3	.333
11.1	8	1	.125	0	.000	4	.500	3	.375
11.4	4	2	.500	0	.000	0	.000	2	.500
11.7	4	2	.500	0	.000	2	.500	0	.000
12.0	4	0	.000	1	.250	1	.250	2	.500
12.3	4	1	.250	0	.000	1	.250	2	.500
12.6	5	1	.200	1	.200	0	.000	3	.600
12.9	2	0	.000	1	.500	0	.000	1	.500
13.2	1	0	.000	0	.000	1	1.0	0	.000
13.5	6	2	.333	1	.167	1	.167	2	.333
13.8	6	3	.500	1	.167	0	.000	2	.333
14.1	4	0	.000	2	.500	1	.250	1	.250
14.4	4	0	.000	1	.250	0	.000	3	.750
14.7	2	2	1.0	0	.000	0	.000	0	.000
15.0	6	2	.333	2	.333	1	.167	1	.167
15.3	1	1	1.0	0	.000	0	.000	0	.000
15.6	1	0	.000	1	1.0	0	.000	0	.000
15.9	2	0	.000	0	.000	0	.000	2	1.0
16.2	3	0	.000	1	.333	0	.000	2	.667
16.5	3	2	.667	0	.000	1	.333	0	.000
16.8	1	1	1.0	0	.000	0	.000	0	.000
17.1	1	0	.000	0	.000	1	1.0	0	.000
17.4	2	1	.500	0	.000	0	.000	1	.500
17.7	1	0	.000	0	.000	1	1.0	0	.000
18.0	4	2	.500	2	.500	0	.000	0	.000
18.3	4	0	.000	3	.750	1	.250	0	.000

Table 8 Continued

Adjusted Distance	Total Calls	NE Sector #	NE Sector %	NW Sector #	NW Sector %	SE Sector #	SE Sector %	SW Sector #	SW Sector %
18.6	1	0	.000	1	1.0	0	.000	0	.000
18.9	3	0	.000	3	.333	3	.334	3	.333
19.2	8	3	.375	0	.000	5	.625	0	.000
19.5	3	0	.000	2	.667	0	.000	1	.333
19.8	3	2	.667	0	.000	0	.000	1	.333
20.1	1	0	.000	0	.000	0	.000	1	1.0
20.4	1	0	.000	1	1.0	0	.000	0	.000
20.7	3	1	.333	1	.334	0	.000	1	.333
21.0	0	0	.250	0	.250	0	.250	0	.250
21.3	3	1	.333	1	.334	1	.333	0	.000
21.6	2	0	.000	0	.000	2	1.0	0	.000
21.9	1	0	.000	1	1.0	0	.000	0	.000
22.2	3	1	.333	2	.667	0	.000	0	.000
22.5	1	0	.000	1	1.0	0	.000	0	.000
22.8	5	1	.200	3	.600	0	.000	1	.200
23.1	0	0	.250	0	.250	0	.250	0	.250
23.4	3	1	.333	2	.667	0	.000	0	.000
23.7	0	0	.250	0	.250	0	.250	0	.250
24.0	1	0	.000	0	.000	1	1.0	0	.000
24.3	1	0	.000	1	1.0	0	.000	0	.000
24.6	2	1	.500	0	.000	0	.000	1	.500
24.9	2	0	.000	1	.500	0	.000	1	.500
25.2	1	1	1.0	0	.000	0	.000	0	.000
25.5	0	0	.250	0	.250	0	.250	0	.250
25.8	2	1	.500	1	.500	0	.000	0	.000
26.1	2	1	.500	1	.500	0	.000	0	.000
26.4	0	0	.250	0	.250	0	.250	0	.250
26.7	1	1	1.0	0	.000	0	.000	0	.000
27.0	2	0	.000	2	1.0	0	.000	0	.000
27.3	1	0	.000	1	1.0	0	.000	0	.000
27.6	1	0	.000	0	.000	0	.000	1	1.0
27.9	1	0	.000	0	.000	0	.000	1	1.0
28.2	3	0	.000	2	.667	0	.000	1	.333
28.5	0	0	.250	0	.250	0	.250	0	.250
28.8	3	0	.000	3	1.0	0	.000	0	.000
29.1	1	0	.000	0	.000	0	.000	1	1.0
29.4	1	0	.000	1	1.0	0	.000	0	.000
29.7	0	0	.250	0	.250	0	.250	0	.250
30.0	0	0	.250	0	.250	0	.250	0	.250

CHAPTER III

THE COMPUTER MODELS

Validation Model

Figure 11 describes the flow of transactions in the validation model of this simulation.

ORIGINATE blocks 200 and 201 provide an exponentially distributed call interarrival rate with a mean of 12 minutes. Two ORIGINATE blocks are used to obtain a higher degree of accuracy than is possible with one block using the mean value of 12. TABULATE block 202 uses the mnemonic IA in its X field to provide a distribution of interarrival times in Table 1.

ADVANCE block 205 uses FUNCTION 2 to assign an appropriate percentage of calls to each of the sectors in the hospital's area of responsibility. These percentages are obtained from Figure 10. SAVEX blocks 206 through 210 uses FUNCTIONS 6 through 10 to assign to X108 the six digit coordinates of a call in a particular sector based on the percentage of calls at a given distance in that sector as found in Table 8.

Blocks 211 through 221 describe the method by which the rectangular distance between call and hospital is determined. As this portion of the program will be common to the following simulations, it will be discussed in detail.

Block 211 assigns to X109 the east-west distance of the call

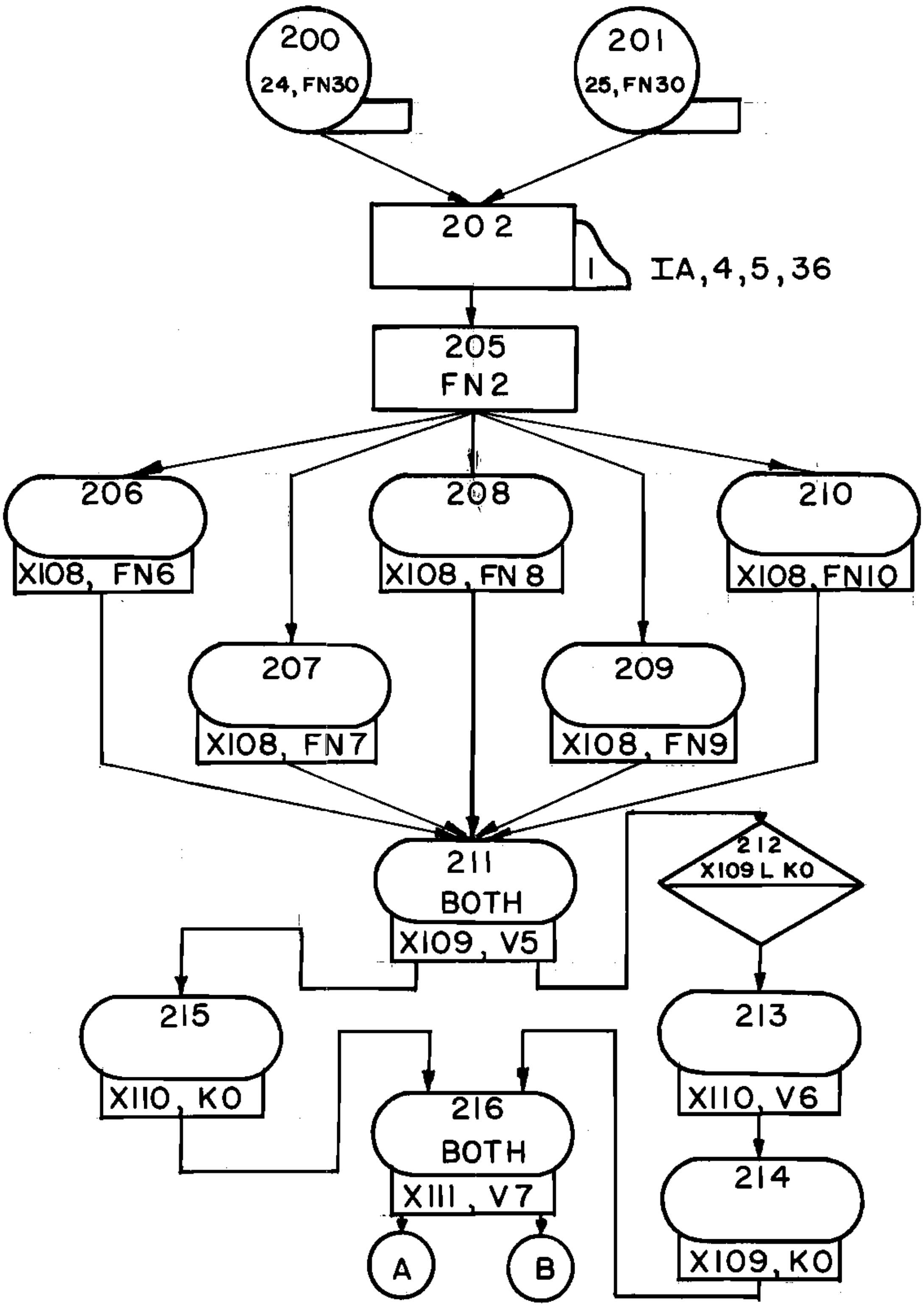


Figure 11. Validation Model Flow Chart.

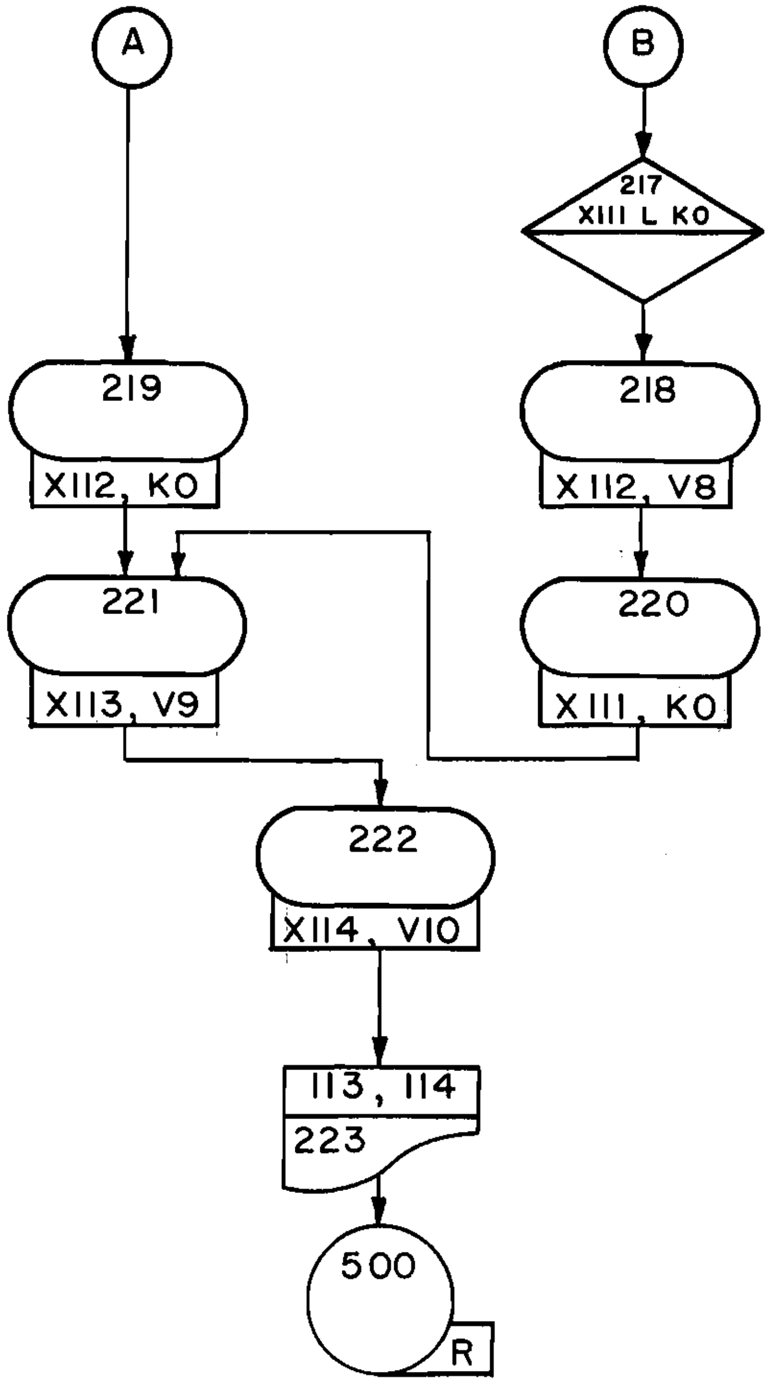


Figure 11 Continued

from the central hospital whose coordinates are assumed to be 400400. X108 which contains the six digit call coordinates is divided by 1000 resulting in the first three digits and 400 is subtracted. The resulting figure, which may be positive or negative, provides an east-west distance. Blocks 212 through 215 insure that this value has a positive sign. If originally negative, the value is subtracted from zero and the now positive figure may be found in X110. If originally positive, the value will be found in X109. Both SAVEX locations will not contain this value as one will always be reset to zero.

Block 216 uses remainder division by 1000 to find the second three digits of the call's six digit coordinates and proceeds through blocks 217 through 219 to provide a positive north-south distance. At SAVEX block 221 the two distances are added.

Since the coordinate system being used is for an expanded system the distance is divided by three in the validation program. In addition the third and sixth digit of a coordinate give distance to the nearest tenth of a mile so the value found in X113 is the actual distance times ten.

Only three blocks remain. At block 222, VARIABLE 10 assigns X114 a service time in minutes. This is found by dividing the distance in X113 by VARIABLE 14 the speed in miles per hour, and by multiplying by 12 to make units consistent and account for a round trip. The delay at the call location is obtained from FUNCTION 15 and added, the delay in returning to service after returning to the hospital is obtained from VARIABLE 16 and added, and finally a constant value of one minute for delay in leaving the hospital after a call is received is added.

Block 223 then prints the total distance times ten found in X113, and the total service time found in X114. The program then terminates.

Results of the Validation Model

Tables 9, 10, and 11 compare the distributions found during the data collection with those generated in the computer simulation. The Kolmogorov Smirnov goodness of fit test was used to test the hypothesis of distribution conformity in each case.

Service times were first tested. Maximum acceptable deviation at a significance level of 0.1 was found to be

$$1.63 \quad \sqrt{128} \quad = \quad .144$$

Since the maximum difference found was .140 at the interval of 41-45 minutes, the hypothesis was not rejected.

Similarly, distance distribution was next tested. Maximum acceptable deviation at a significance level of 0.5 was found to be

$$1.36 \quad \sqrt{\frac{539 + 769}{539\ (769)}} \quad = \quad .0764$$

Since the maximum difference found was .028 at a distance of 3.7 miles the hypothesis of distribution conformity was not rejected.

Finally, the distribution of the time between calls was tested. Maximum acceptable deviation at a significance level of 0.5 was found to be

Table 9. Validation of Service Times

Interval	Sample Number	Sample Cumulative Percentage	Simulation Number	Simulation Cumulative Percentage	Difference
1-5	0	.000	1	.008	.008
6-10	3	.023	4	.039	.016
11-15	7	.078	7	.094	.018
16-20	18	.219	11	.180	.039
21-25	22	.391	16	.305	.086
26-30	14	.500	15	.422	.078
31-35	15	.617	10	.500	.117
36-40	10	.695	11	.585	.110
41-45	11	.781	7	.641	.140
46-50	7	.836	11	.727	.109
51-55	9	.906	11	.813	.093
56-60	4	.938	4	.843	.095
61-65	3	.961	7	.898	.063
66-70	4	.992	4	.930	.062
71-75	0	.992	3	.953	.039
76-80	0	.992	1	.961	.031
81-85	0	.992	0	.961	.031
86-90	0	.992	5	1.00	.008
91-95	0	.992	-	-	.008
96-100	0	.992	-	-	.008
101-105	0	.992	-	-	.008
106-110	1	1.00	-	-	.000

Table 10. Validation of Distance Distribution

Distance	Simulation Number	Cumulative Percentage	Sample Cumulative Percentage	Difference
.1	3	.004	.000	.004
.2	5	.010	.007	.003
.3	11	.025	.019	.006
.4	14	.043	.033	.010
.5	9	.055	.058	.003
.6	10	.068	.071	.003
.7	12	.083	.089	.006
.8	9	.095	.109	.014
.9	14	.113	.134	.021
1.0	18	.137	.147	.010
1.1	14	.155	.167	.012
1.2	27	.190	.191	.001
1.3	17	.212	.210	.002
1.4	20	.238	.232	.006
1.5	18	.261	.256	.005
1.6	30	.300	.284	.016
1.7	14	.319	.314	.005
1.8	18	.342	.340	.002
1.9	19	.367	.373	.006
2.0	19	.391	.416	.025
2.1	23	.421	.436	.015
2.2	25	.454	.453	.001
2.3	12	.469	.469	.000
2.4	19	.694	.495	.001
2.5	17	.516	.506	.010
2.6	26	.550	.529	.021
2.7	16	.571	.553	.018
2.8	6	.579	.579	.000
2.9	14	.597	.599	.002
3.0	8	.607	.618	.011
3.1	10	.620	.642	.022
3.2	13	.637	.661	.024
3.3	10	.650	.675	.025
3.4	15	.668	.688	.020
3.5	4	.675	.698	.023
3.6	14	.693	.714	.021
3.7	6	.701	.729	.028
3.8	7	.710	.737	.027
3.9	5	.717	.744	.027
4.0	6	.724	.751	.027
4.1	10	.737	.759	.022

Table 10 Continued

Distance	Simulation Number	Cumulative Percentage	Sample Cumulative Percentage	Difference
4.2	8	.748	.768	.020
4.3	10	.761	.772	.011
4.4	10	.774	.774	.000
4.5	10	.787	.785	.002
4.6	8	.797	.796	.001
4.7	3	.801	.803	.002
4.8	5	.807	.811	.004
4.9	10	.821	.814	.007
5.0	10	.834	.826	.008
5.1	4	.839	.827	.012
5.2	1	.840	.829	.011
5.3	7	.849	.833	.016
5.4	7	.858	.839	.019
5.5	5	.865	.844	.021
5.6	5	.871	.846	.025
5.7	3	.875	.848	.027
5.8	0	.875	.851	.024
5.9	3	.879	.853	.026
6.0	2	.882	.861	.021
6.1	3	.886	.868	.018
6.2	4	.891	.870	.021
6.3	3	.895	.876	.019
6.4	3	.898	.891	.007
6.5	5	.905	.896	.009
6.6	4	.910	.902	.008
6.7	3	.914	.904	.010
6.8	0	.914	.904	.009
6.9	3	.918	.911	.007
7.0	2	.921	.911	.010
7.1	1	.922	.917	.005
7.2	2	.925	.920	.005
7.3	2	.927	.922	.005
7.4	10	.940	.928	.012
7.5	0	.940	.930	.010
7.6	5	.947	.939	.008
7.7	1	.948	.939	.009
7.8	1	.949	.944	.005
7.9	3	.953	.944	.009
8.0	1	.955	.946	.009
8.1	1	.956	.948	.008
8.2	5	.962	.952	.010
8.3	4	.967	.956	.011

Table 10 Continued

Distance	Simulation Number	Cumulative Percentage	Sample Cumulative Percentage	Difference
8.4	0	.967	.957	.010
8.5	2	.970	.957	.013
8.6	1	.971	.961	.010
8.7	1	.973	.965	.008
8.8	2	.975	.965	.010
8.9	1	.977	.967	.010
9.0	1	.978	.970	.008
9.1	2	.980	.972	.008
9.2	1	.982	.974	.008
9.3	2	.984	.976	.008
9.4	1	.986	.982	.004
9.5	4	.991	.982	.009
9.6	1	.992	.987	.005
9.7	3	.996	.989	.007
9.8	0	.996	.991	.005
9.9	1	.997	.991	.006
10.0	2	1.00	1.00	.000

Table 11. Validation of Time Between Calls

Interval	Sample Number	Sample Cumulative Percentage	Simulation Number	Simulation Cumulative Percentage	Difference
0-4	32	.305	162	.325	.020
5-9	24	.533	104	.533	.000
10-14	15	.676	57	.647	.029
15-19	12	.791	67	.782	.009
20-24	8	.867	33	.848	.019
25-29	3	.895	27	.902	.007
30-34	5	.943	13	.928	.015
35-39	2	.962	5	.938	.024
40-44	0	.962	14	.966	.004
45-49	1	.971	7	.980	.009
50-54	1	.981	7	.994	.013
55-59	0	.981	2	.998	.017
60-64	0	.981	1	1.00	.019
65-69	1	.991	-	-	.009
70-74	0	.991	-	-	.009
75-79	0	.991	-	-	.009
80-84	0	.991	-	-	.009
85-89	1	1.00	-	-	.000

$$1.36 \sqrt{\frac{499 + 105}{499\ (105)}} = .146$$

Since the maximum difference found was .029 in the 10-14 minute interval, the hypothesis of distribution conformity was again not rejected.

Expanded Centralized System

The expanded centralized system enlarges the area from which a call may be received by a factor of three. It also takes into account the number of ambulances in the system, false calls and calls needing assistance but not transportation, the assumption that beyond 10.8 miles from the central hospital ambulance speed is changed, and that an ambulance will be available for further service from the scene of a call not actually using the ambulance for transportation. Figure 12 depicts the flow of transactions through the model for the expanded centralized system. For ease of illustration, only facility three is diagrammatically shown in its entirety. The remaining facilities run parallel to facility three and may be examined more closely by referring to Appendix B.

The initialization portion of the program and sets SAVEX locations 1 through 10 and 99 equal to 400400, the coordinates of the central hospital and hence the initial location of all ambulances in the system. Eleven SAVEX locations are used as the system will start with six ambulances and this number will be increased until no queue is formed during the simulation. SAVEX blocks 1 through 10 will be used to designate the location from which an ambulance

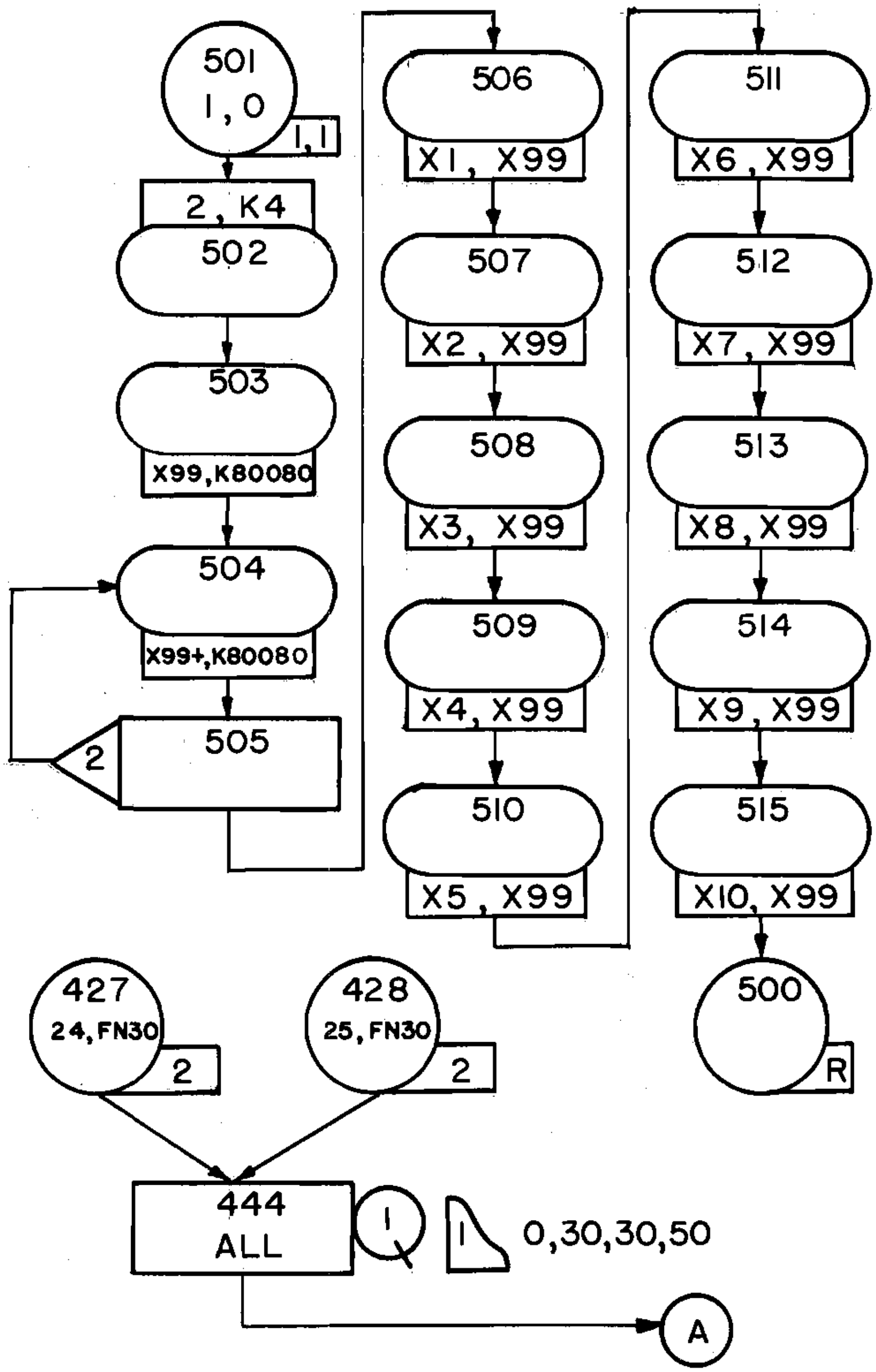


Figure 12. Expanded Centralized System Flow Chart

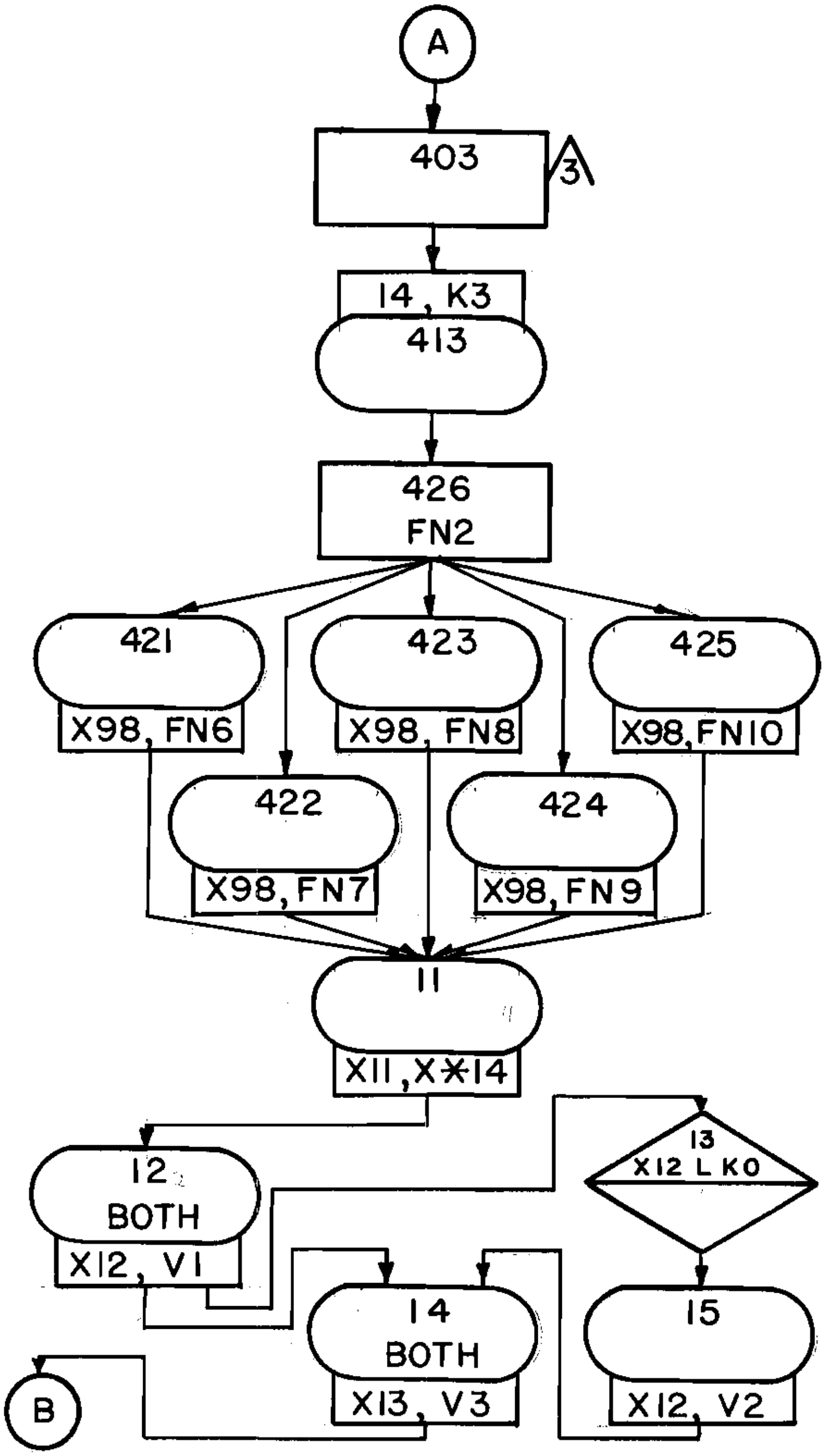


Figure 12 Continued

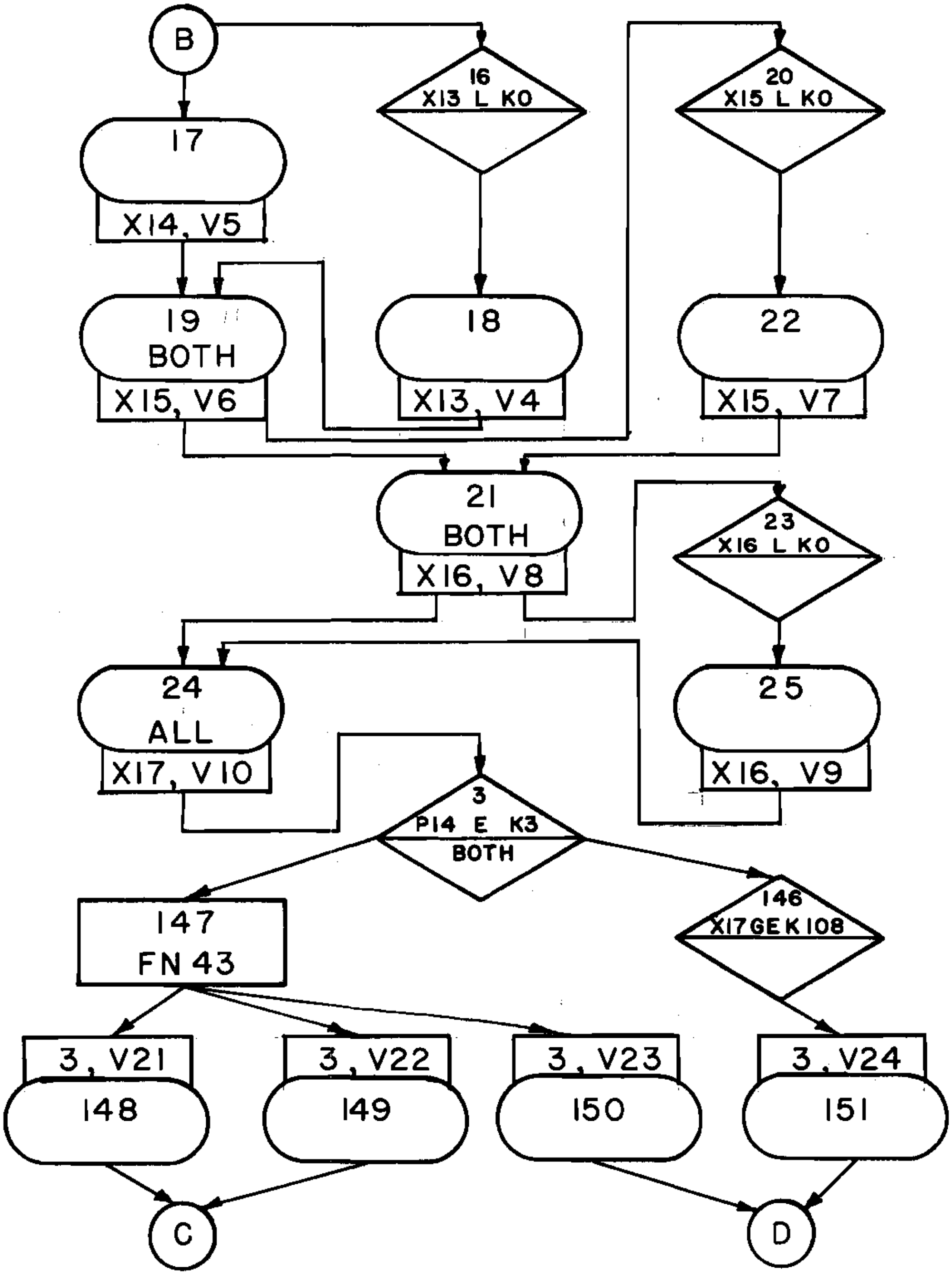


Figure 12 Continued

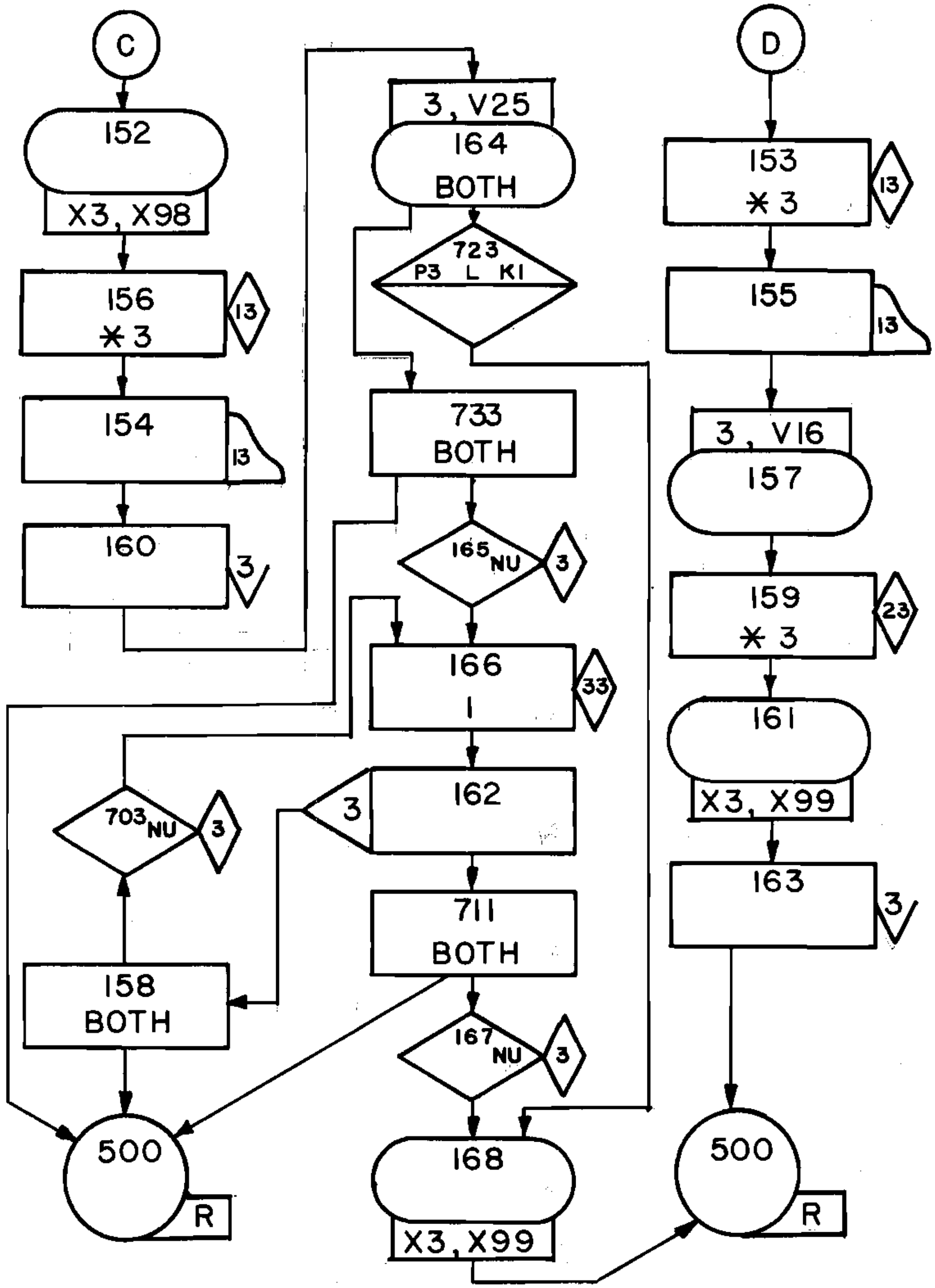


Figure 12 Continued

answers a call. This location may change as the result of a false call or a call needing assistance but not transportation. SAVEX block 99 is therefore provided to return SAVEX locations 1 through 10 to the initial coordinates when required.

Figure 15 shows the transactions being originated at blocks 427 and 428 going to a common QUEUE block 444. The selection mode at block 444 is ALL and up to ten SEIZE blocks such as block 403 follow and represent ambulances in the system. The SEIZE blocks are followed by an ASSIGN block where parameter 14 is assigned a value of from one to ten depending on which facility has been seized. Transactions are then routed to ADVANCE block 426 where FUNCTION 2 sends an appropriate percentage to each of five sectors. Blocks 421 through 425 provide the coordinates of a call in each sector.

All transactions then go to SAVEX block 11 where X11 is given the value found in the SAVEX location specified by parameter 14, the location of the ambulance when a call is received. Blocks 12 through 18 are then used to determine the rectangular distance from ambulance to call, and this distance is placed in SAVEX location X14. The distance between the call and the hospital is similarly obtained using blocks 19 through 25 and this distance is placed in SAVEX location X17.

SAVEX block 24 has an ALL selection mode and up to ten COMPARE blocks such as block three follow. These blocks determine which facility has been seized for proper routing of the transaction. From this COMPARE block transactions are tested at a following COMPARE block such as 146 to determine if the distance from hospital to call is greater than or equal to 10.8 miles. If so, an appropriate hold time is obtained using VARIABLE 24 and is assigned to parameter three. If the distance is less than 10.8 miles the transaction will go to ADVANCE block 143 where an appropriate number of false calls, calls needing assistance but not transportation, and remaining real calls will be routed to ASSIGN blocks 148 through 150. Again, parameter three will be assigned an appropriate time by VARIABLES 21 through 23.

ASSIGN blocks 150 and 151 thus contain a delay for a real call. VARIABLES 23 and 24 will provide the time needed to go to the call location and from the location to the hospital, plus delays at the call scene and the delay getting into service. This total time comprises the actual service time. HOLD block 153 will hold the transaction the length of time specified by parameter three. ASSIGN block 157 then assigns parameter three a time obtained from VARIABLE 16 which is the delay in returning to service after reaching the hospital. HOLD block 159 further holds the transaction this length of time.

Since real calls terminate at the hospital SAVEX location X3 is again given the coordinates of the central hospital in block 161, and block 163 releases facility three. TABULATE block 155 will provide a record of the actual service time for the call when no queue exists.

Block 148 and 149 are used by transactions in which termination of service is not at the central hospital. After assigning parameter three an appropriate time the transaction is routed to block 152 where SAVEX location X3, the ambulance location, is given the same coordinates as the call. From there the transaction is held at block 156, tabulated, and the facility is released at block 160. Parameter three is then assigned a delay by VARIABLE 25 which consists of one half the time needed by the ambulance to travel from the call scene back to the hospital.

It will be assumed that an incoming call will be answered from the scene of the previous call until half the time needed to return to the hospital has passed.

The transaction is next tested at COMPARE block 723. Since the value now found in parameter three will be used in a LOOP block it cannot be zero. If it is less than one, the ambulance is returned to the central hospital and the transaction is terminated. If parameter three is greater than or equal to one the transaction goes to ADVANCE block 733.

It next encounters GATE block 165. If facility three is not in use, it enters block 165. If the facility is in use, the new call was answered from the scene of the original call and the original transaction is terminated.

From block 165, the transaction goes to HOLD block 166. Blocks 166, 162, 158, and 703 hold the transaction in one minute increments up to the limit specified by parameter three. If a new transaction seizes facility three during this holding time, the original transaction is immediately terminated. If no new transaction enters facility three then SAVEX location X3 is again given the coordinates of the central hospital and the transaction is terminated.

Results of the Expanded Centralized System

With seven ambulances in the system, 55 percent of the calls received did not spend time in a queue. Average time in a quque for all entries was 19.28 minutes. Average service time was 50.11 minutes. Average service time plus queue time was 69.39 minutes. Ambulance utilization was 61.82 percent.

The number of ambulances in the system was next increased to eight. With eight ambulances in the system, 75 percent of the calls received did not spend time in a queue. Average time in a queue for all entries was 3.55 minutes. Average service time was 48.81 minutes. Average service time plus queue time was 52.36 minutes. Ambulance utilization was 53.11 percent.

The number of ambulances in the system was then increased to nine. With nine ambulances in the system, more than 99 percent of the calls received did not spend time in a queue. Average time in a queue for all entries was 0.20 minutes. Average service time was 49.47 minutes. Average service time plus queue time was 49.67 minutes. Since the difference between these last two times is less than half a minute, the number of ambulances in the system was not increased beyond nine.

Average ambulance utilization at this point was 49.8 percent which compares favorably to the optimum utilization figure of 42 percent found in the New York Study (16).

Decentralized System with Queues in Sectors

Six ambulances were assumed in this model. It was further assumed that ambulances would answer only calls received from their sector. This last assumption will lead to a system which is extremely inefficient in terms of the number of ambulances needed if queues are not desirable. For example, if the first six calls received are all from the same satellite sector, five will be forced to wait for service from that sector's ambulance. At the same time, the other five ambulances in the system will be idle.

Though inefficient, the model will provide a minimum service time for an all ground ambulance system using the decentralized system proposed in this thesis. Though false calls and calls needing assistance but not transportation were included in the simulation, it was assumed that the ambulance would return to its original location before answering another call, and would not be dispatched from the scene of the two types of calls just mentioned.

The flow chart for the simulation of a decentralized ambulance system with queues allowed in each sector is shown in Figure 13.

Figure 13 indicates three ORIGINATE blocks. Block 501 generates one transaction which sets SAVEX locations 1 through 6 to the six digit coordinate of each of the four satellite locations and the coordinates of the two ambulances which remain at the central hospital. These coordinates are printed by block 523 to insure they are correct and the transaction then terminates.

ORIGINATE blocks 10 and 11 then begin producing transactions. These transactions are routed to ADVANCE block 14 where an appropriate percentage is assigned to each sector.

Again, for ease of illustration, only facility three will be shown. From block 14, the transactions go to five QUEUE blocks. Each of the satellite locations has an individual queue while the two

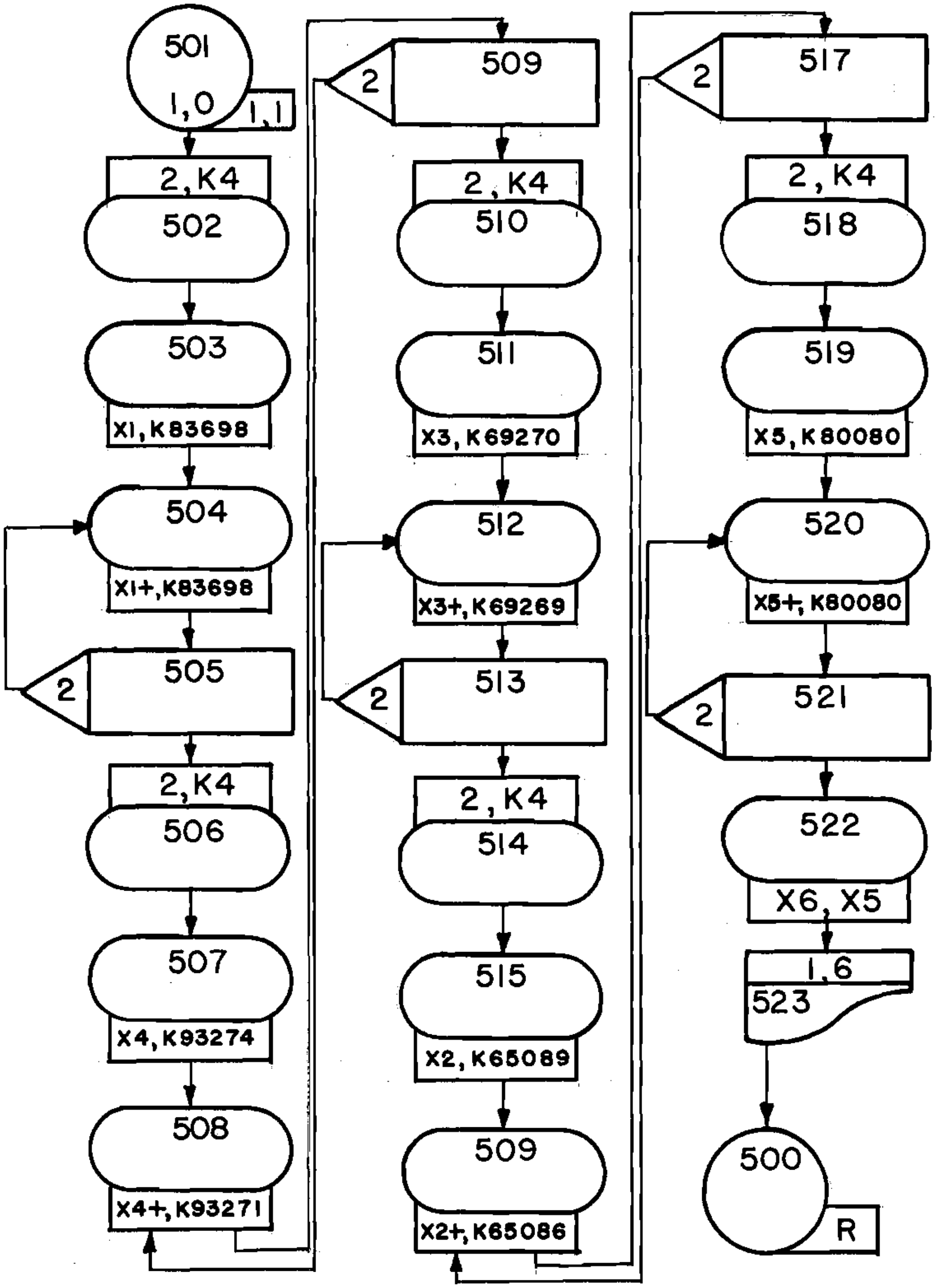


Figure 13. Decentralized with Queues Flow Chart

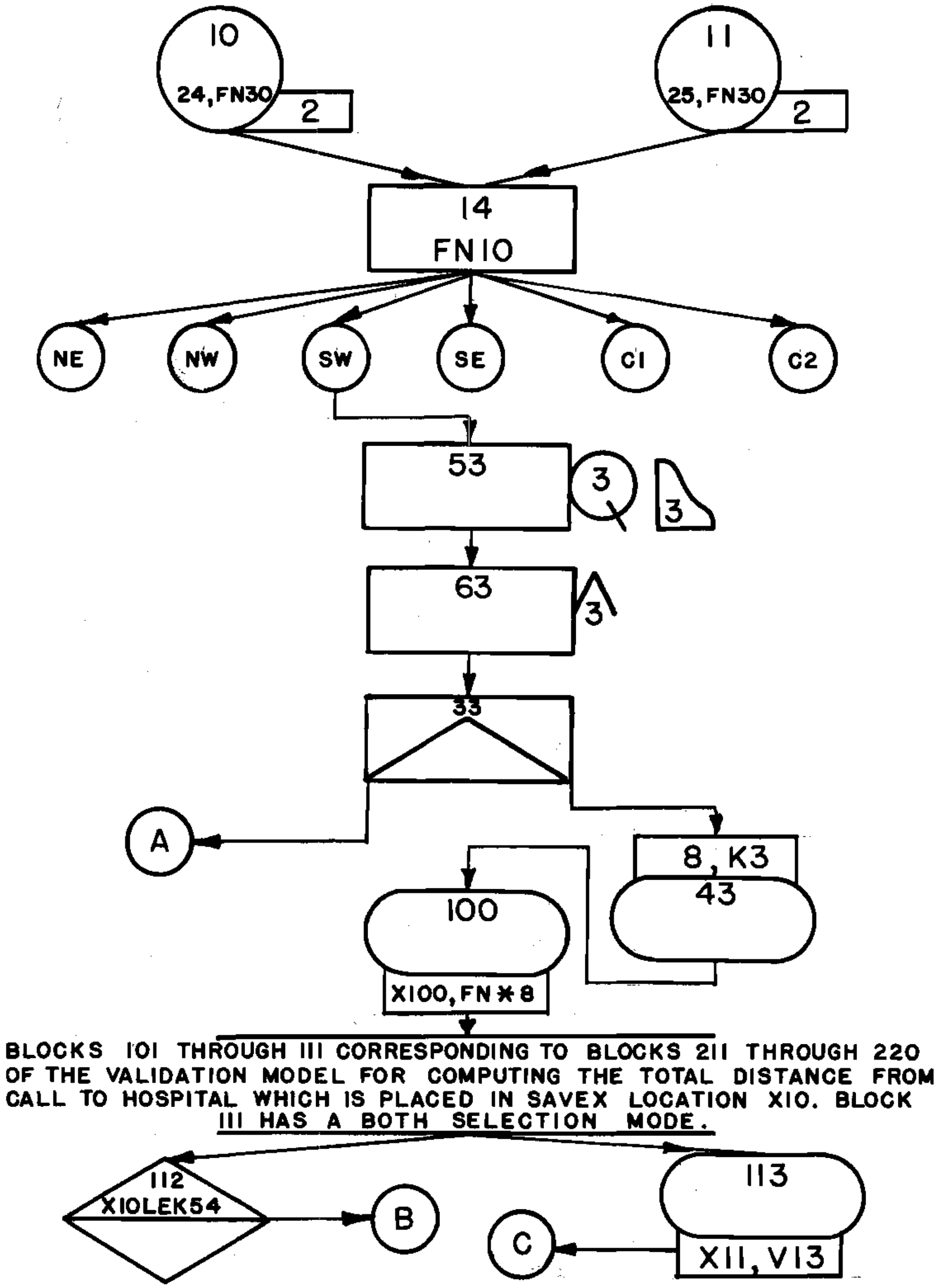


Figure 13 Continued

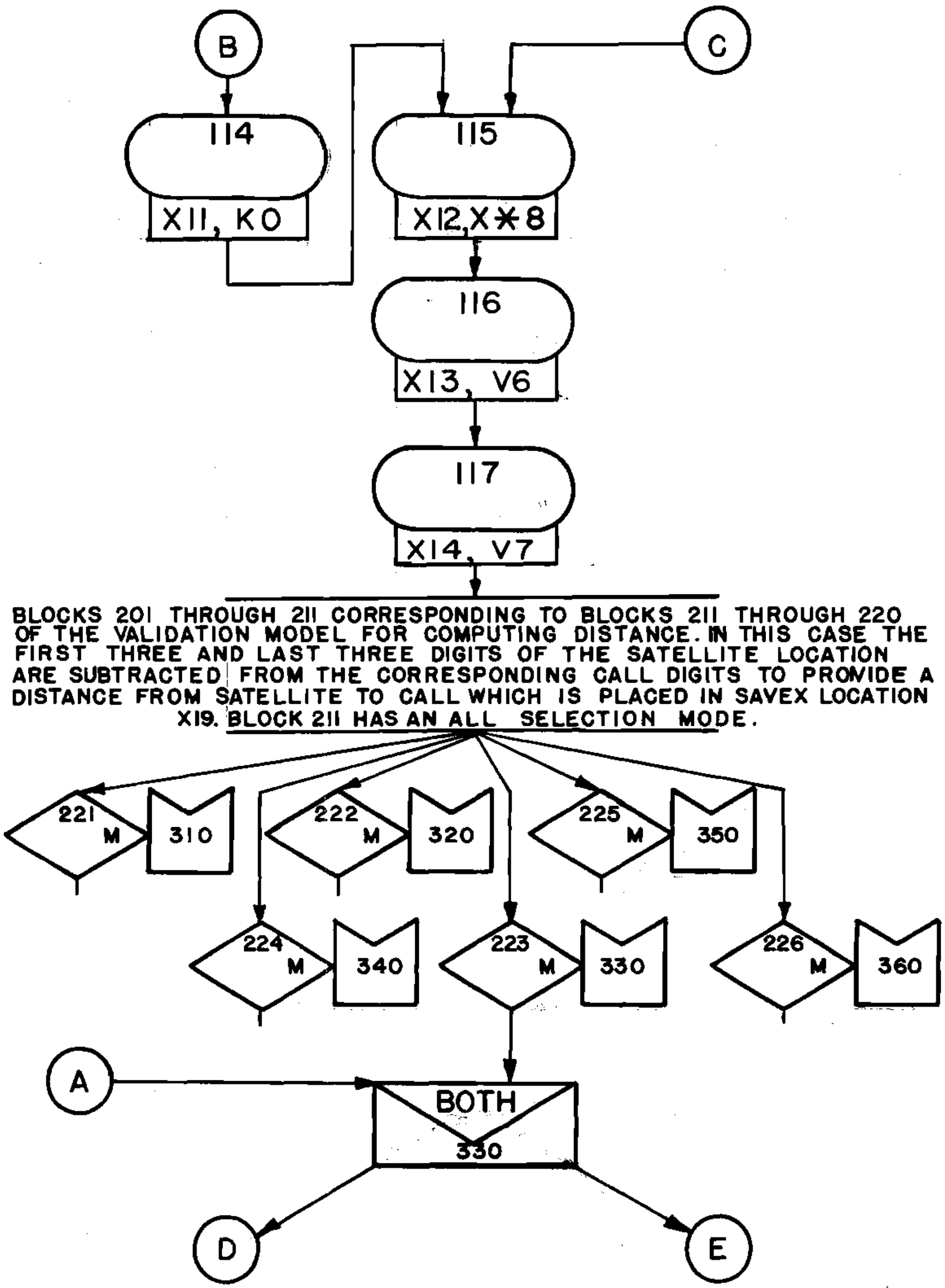


Figure 13 Continued

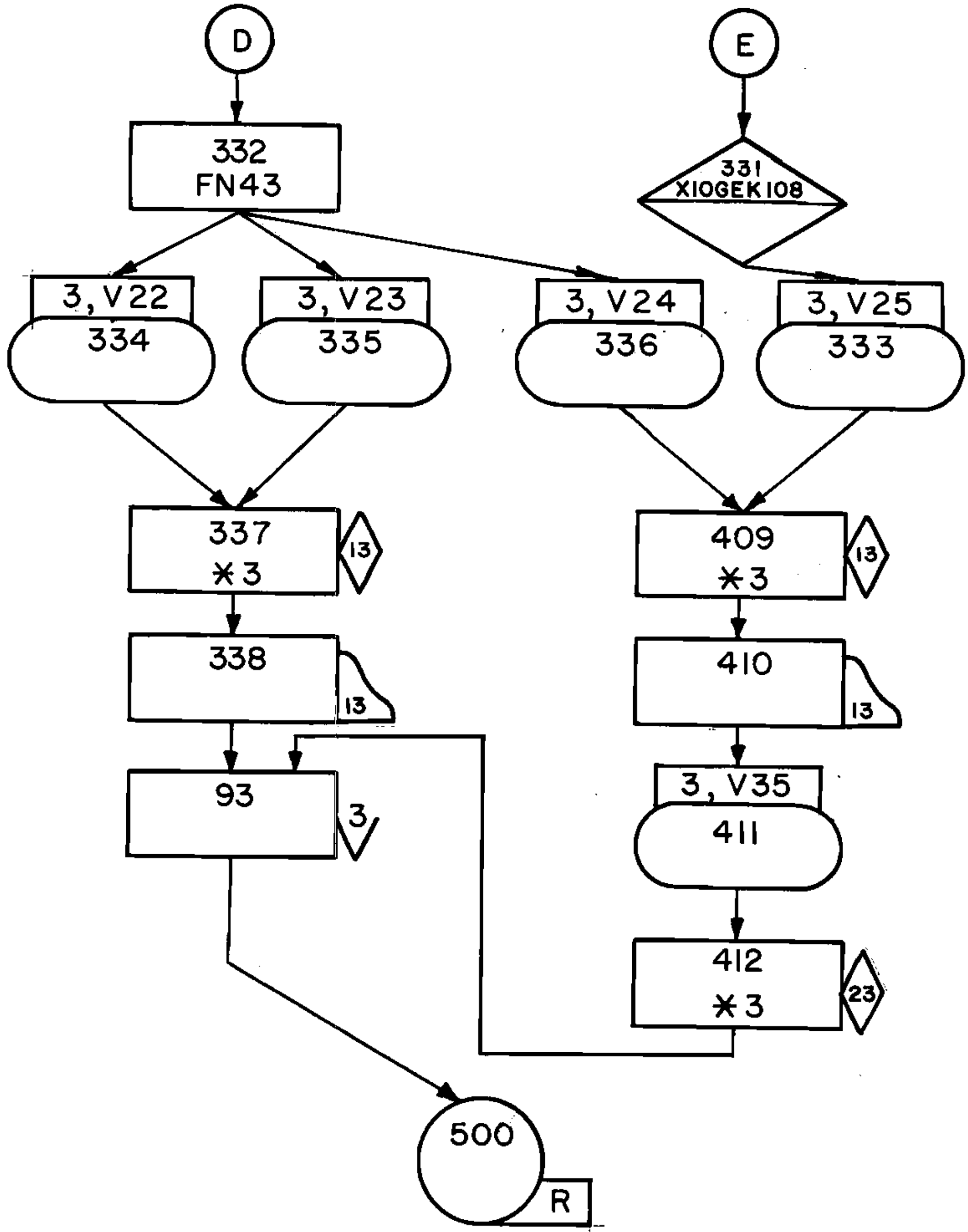


Figure 13 Continued

ambulances remaining at the central hospital have a common queue. From each of the satellite queues, such as block 53, the transactions attempt to enter a corresponding facility, in the case shown SEIZE block 63. The central queue routes transactions to two SEIZE blocks with a BOTH selection mode.

As with the expanded centralized system, the transaction leaving a SEIZE block is split as in block 34. Parameter 8 is then assigned a number corresponding to the facility seized. All transactions are then routed to SAVEX block 100 where X100 is assigned a value from a FUNCTION specified by parameter 8. FUNCTIONS 1 through 6 correspond to FUNCTIONS 6 through 10 and a second FUNCTION 10 from the first two programs. X100, therefore, will contain a six digit call coordinate.

The transaction then goes through blocks 101 through 111 where the rectangular distance from the central hospital to the call location is computed and placed in X10.

Block 111 contains a BOTH selection mode and at COMPARE block 112 the distance in X10 is tested to determine if it is less than or equal to 5.4 miles. If so the call will be answered by an ambulance from the central sector and the distance and time between satellite and central hospital will be zero. If greater than 5.4 miles the distance between satellite and call is 10.8 miles and an appropriate time is compute. The time for an ambulance to travel from the central hospital to the satellite location is therefore found in SAVEX location X11.

From either block 113 or 114 the transaction is directed to SAVEX block 115 where X12 is assigned the six digit coordinates of the satellite ambulance's location. Block 116 provides the first three digits of this coordinate, and block 117 provides the second three digits.

Blocks 201 through 211 are used to compute the rectangular distance between the satellite location and the call similarly to the method used in blocks 211 through 220 of the validation model.

At SAVEX block 211, X19 is assigned the distance between satellite and call. The selection mode at block 211 is ALL, and similarly to the model for an expanded centralized system, six GATE blocks follow. Again these are used to insure that the original transaction reaches its appropriate ASSEMBLE block first. An ASSEMBLE block such as 330 then follows the GATE block.

From the ASSEMBLE blocks to the TERMINATE block the program basically duplicates the portion of the expanded centralized system following its ASSEMBLE blocks. Appropriate parameters are assigned hold times based on the three distances involved, speeds, and delays. HOLD blocks hold a transaction the length of time specified by these parameters, and then facilities are released. Once again total time in the system, time in the queues, actual time in a facility, and time to return to service after the patient has been brought to the hospital will be tabulated.

To account for the existence of a private ambulance service the QUEUE blocks are given a BOTH selection mode, ADVANCE block 99 is added, and a TERMINATE block follows the ADVANCE block.

Results of the Decentralized System with Queues in Sectors

The average service time for all calls answered was 41.00 minutes. Only 1.28 percent of the calls received did not spend time in a queue. Average time spent in the queue was 2568.0 minutes. Average service time plus queue time was 2609.0 minutes. Ambulance utilization was 100 percent.

The model proved to be so inefficient that only 301 transactions were able to get through an initialized system. At that point, there were more than 1000 transactions remaining in the system, primarily in queues. As the computer can not process more than 1000 transactions in the system at one time, the program was automatically terminated.

Decentralized System with Priorities and Helicopters

The decentralized system with priorities takes into account all those considerations mentioned in the expanded centralized system. In addition, it establishes priorities by distance. If a call is received in a sector when that particular sector's ambulance is in use, the next closest ambulance to that call will provide assistance.

Initially, nine ambulances will be simulated as this was the number determined to be the minimum needed to provide service in a centralized system without a queue. This number will be progressively decreased to determine if a reduction is possible in the new system.

The simulation of helicopters will be a part of the decentralized system with priorities. By initially setting VARIABLE 12 to 15, the simulation will be first run without helicopters. VARIABLE 15 provides the status of those facilities representing helicopters and is defined as

$$K8 * F14 + K4 * F42 + K2 * F43 + F44$$

Helicopter ambulances will be used in answering calls at a distance of 10.8 miles and further from the central hospital. Two-step evacuation using the satellite helipads given in Figure 10 will be simulated. Initially, one helicopter ambulance will be added to the system and this number will be increased to a maximum of four.

Basically, the program is very similar to those already discussed. Call generation, distance calculations, and ambulance delays (including helicopter ambulances) are handled in much the same way as may be found in the flow chart for the expanded centralized system.

The major difference found in the model for a decentralized system with priorities and helicopters is the method by which the closest ambulance is found if the primary sector ambulance is in use. The complexity and length of the model dictates that a block diagram rather than a flow chart for the entire model be provided. The block diagram is shown in Figure 14.

To assist in understanding the model for a decentralized system with priorities and helicopters, the following SAVEX locations, VARIABLES, and FUNCTIONS are further explained. All distances defined are times ten because of the integer limitations of GPSS.

X100 contains the six digit call coordinates.

X41 through X44 contain the total time flown by the helicopter for maintenance purposes.

X62 contains the shortest distance to a helipad from a call received at a distance of 10.8 miles or more from the central hospital.

X64 contains the distance from the call to the central hospital.

X65 contains the distance from the call to the ambulance answering.

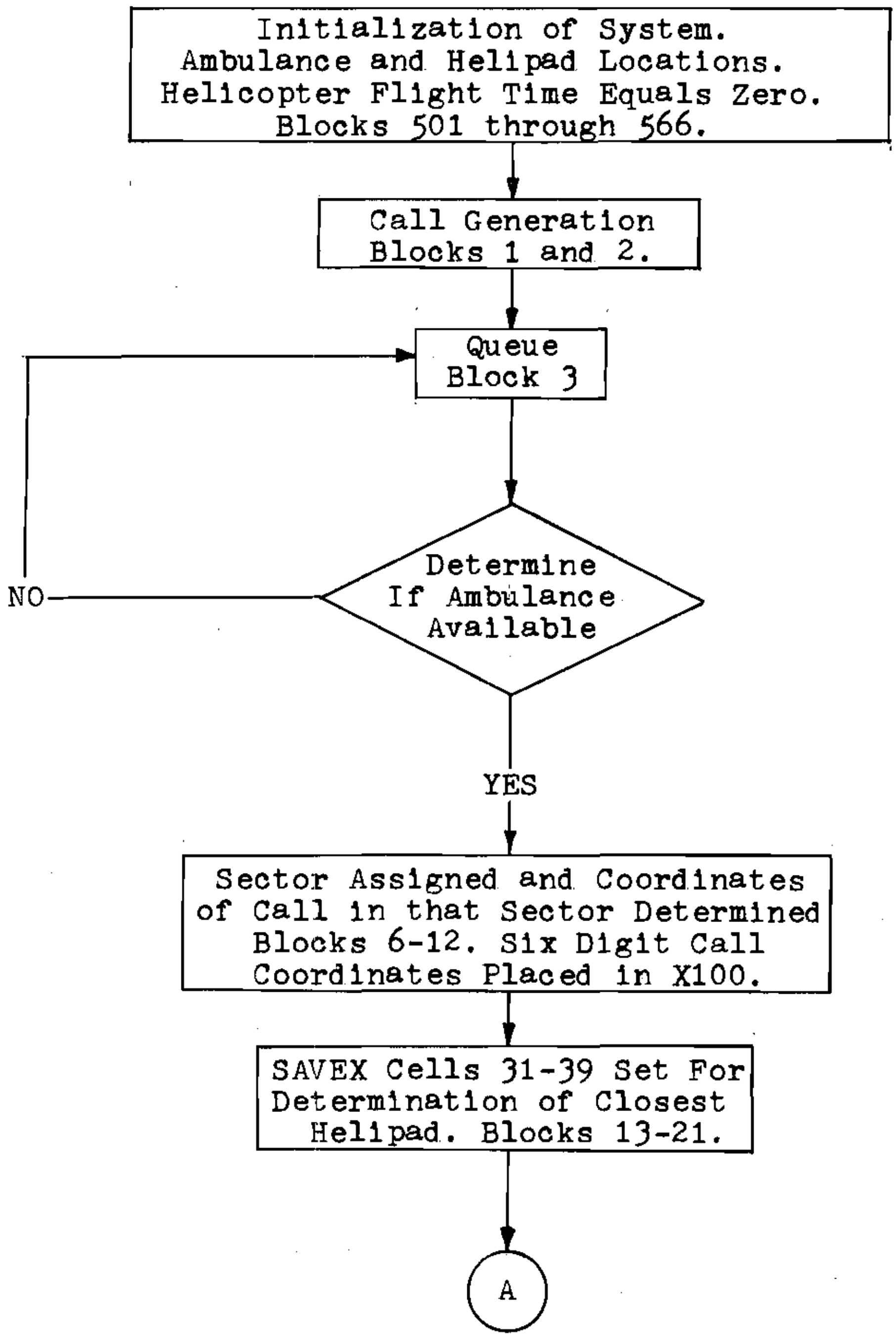


Figure 14. Block Diagram for Decentralized System with Priorities and Helicopters

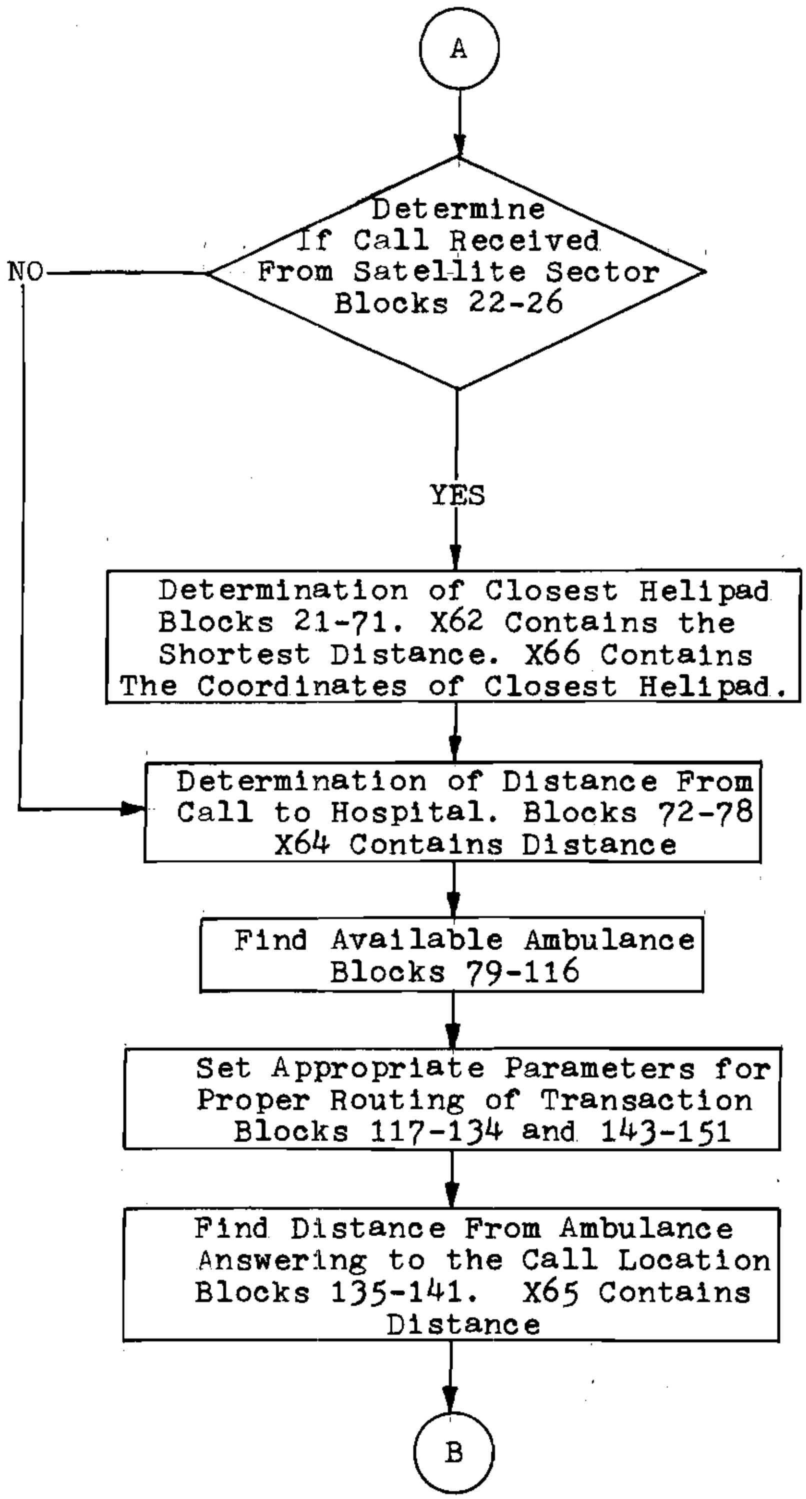


Figure 14 Continued

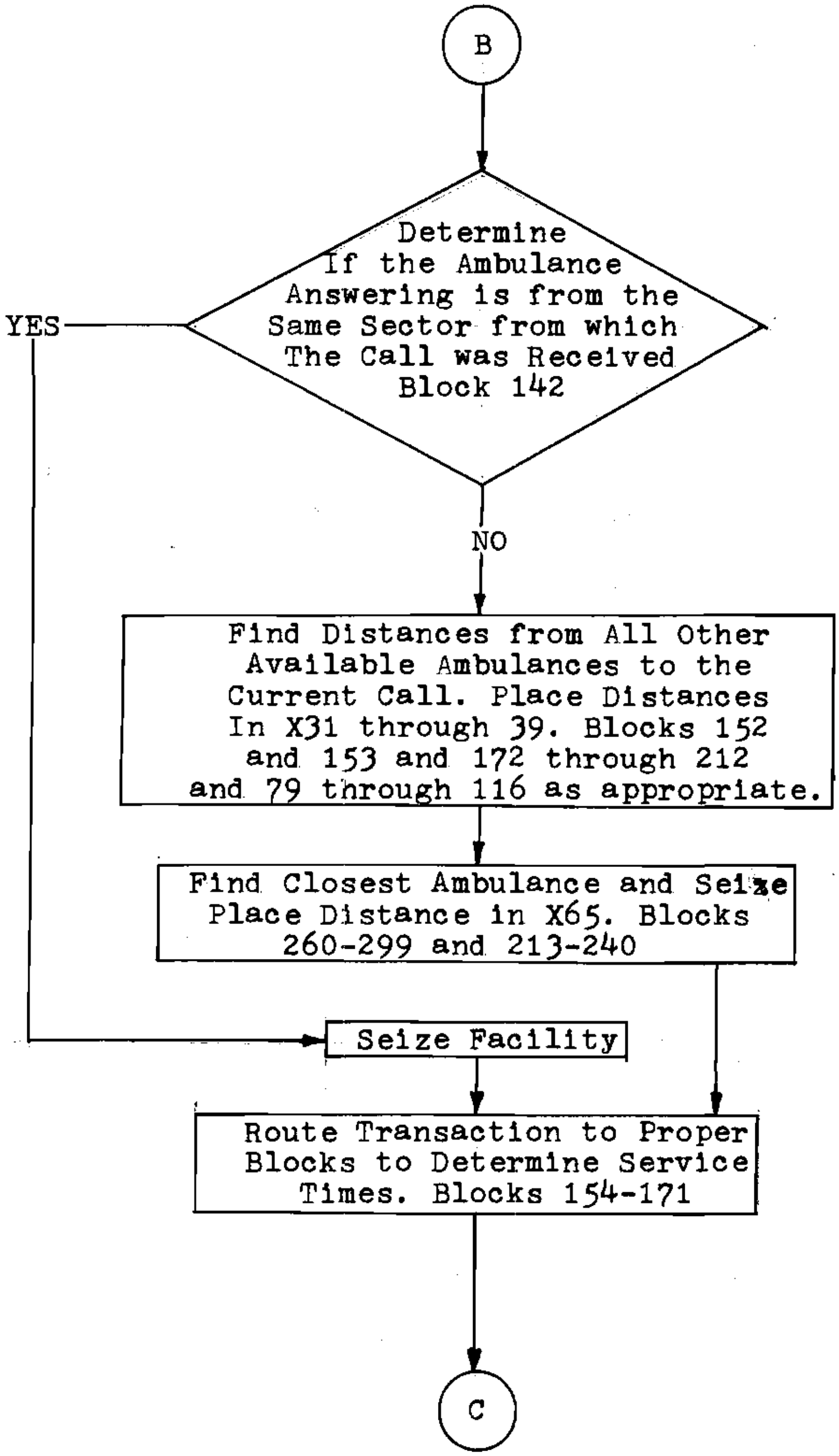


Figure 14 Continued

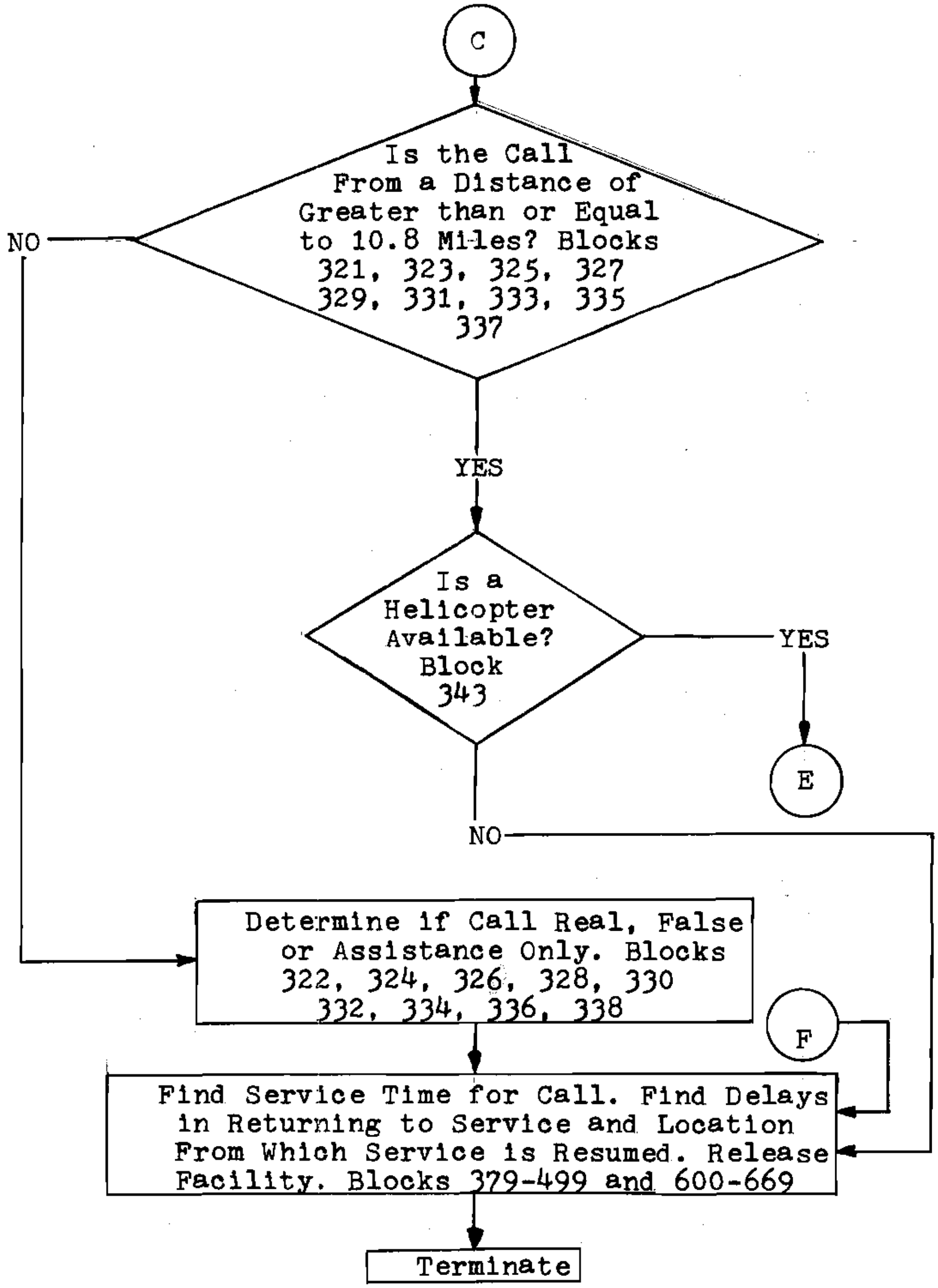


Figure 14 Continued

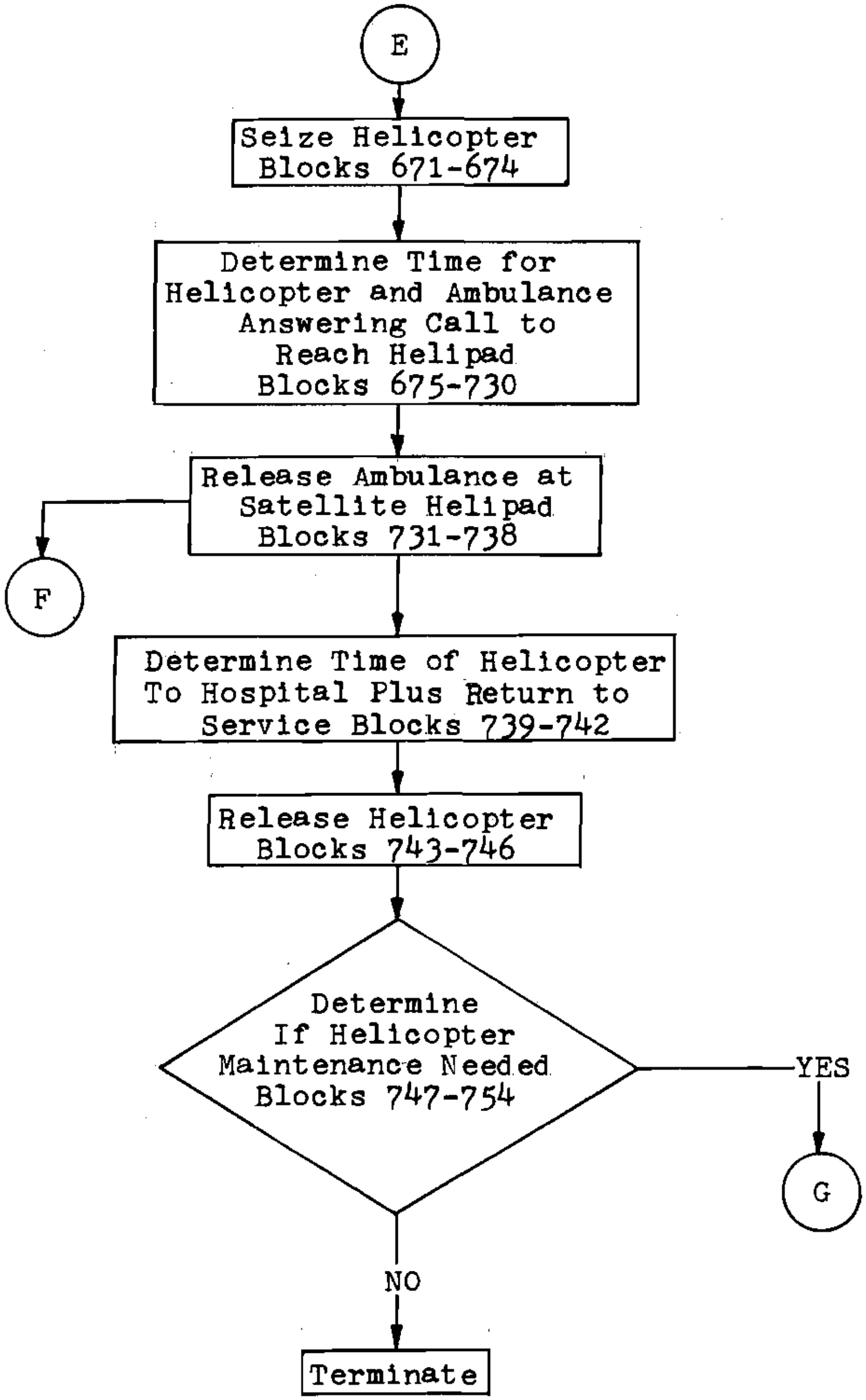


Figure 14 Continued

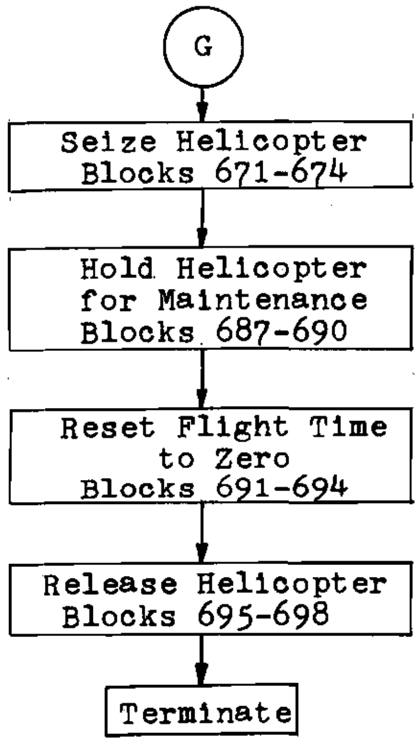


Figure 14 Continued

X66 contains the coordinates of the nearest helipad to a call.

X67 contains the distance from the nearest helipad to a call to the original satellite location of the ambulance answering.

X69 contains the distance from a false call or call not needing transportation to the original satellite location of the ambulance answering.

X70 contains the time needed for a helicopter to take off, fly to a helipad, plus transfer delay at that helipad.

X71 contains the time needed for an ambulance to go to a call, pick up the patient, proceed to the nearest helipad, plus transfer delay at the helipad.

X21 contains the original coordinates of ambulances located in the central sector.

X24 contains the original coordinates of the ambulance located in the northeast sector.

X25 contains the original coordinates of ambulances located in the southeast sector.

X27 contains the original coordinates of the ambulance located in the southwest sector.

X28 contains the original coordinates of ambulances located in the northwest sector.

$$VI = K16 * F5 + K8 * F4 + K4 * F3 + K2 * F2 + F1$$

This provides the status of facilities six through nine which also represent ambulances.

$$V12 = K8 * F41 + K4 * F42 + K2 * F43 + F44$$

This provides the status of facilities 41 through 44 which represent helicopters.

V14 = the ambulance speed in miles per hour at distances within 10.8 miles of the central hospital.

V16 = the ambulance delay in minutes after reaching the hospital with a patient and before returning to service.

FN17 = the delay at the scene of a call needing assistance but not transportation.

FN15 = the delay at the scene of a real call.

$$V17 = X65 * K6/V14 + K5$$

This provides the time in minutes to the scene of a false call plus a five minute delay.

$$V18 = X65 * K6/V14 + FN17 + K1$$

This provides the time in minutes to the scene of a call needing assistance but not transportation, plus the delay at the call location, plus a one minute delay.

$$V19 = X65 * K6/V14 + FN15 + X64 * K6/V14 + K1$$

This provides the time in minutes to a real call located less than 10.8 miles from the hospital, plus the delay at the call location, plus the time returning to the hospital, plus a one minute delay.

$$V21 = X64 * K3/V14$$

This provides one half of the time to return to the hospital from the scene of a false or assistance only call.

$$V22 = X64 - K108$$

This provides that distance from the hospital to call greater than 10.8 miles for calls at a distance greater than or equal to 10.8 miles from the central hospital.

$$V23 = X65 - V22$$

This provides that part of the distance from the ambulance to a call less than 10.8 miles for a call received from a distance greater than or equal to 10.8 miles from the central hospital.

$$V20 = V22 * K6/K25 + K648/V14 + V23 * K6/V14 + FN15 + K1$$

This provides the time in minutes to a real call at a distance greater than or equal to 10.8 miles from the central hospital, plus delays, plus the time back to the hospital. It accounts for the two different ambulance speeds assumed for distances less than or greater than 10.8 miles.

$$V24 = X62 * K/3K25 + X65 * K3/K25 + FN15 + K6$$

This provides the time to a call plus delay at the call scene, plus time to the nearest helipad, plus transfer delay at the helipad, plus a one minute delay.

$$V25 = X67 - K108$$

This provides that part of the distance from a helipad to the central hospital greater than 10.8 miles.

$$V26 = X67 * K3/K50$$

This provides one half the time from a helipad to a satellite location.

$$V27 = V25 * K3/K50 + K324/V14$$

This provides one half the time from a helipad to the central hospital.

$$V29 = X69 * K3/V14$$

This provides one half the time to return to a satellite location from the scene of a false or assistance only call.

When helicopters are added to the model, it is possible that an ambulance may answer a call from a helipad. Since either the sector's ambulance or the closest ambulance will answer a call, it may be assumed that the majority of the calls answered from satellite locations will be at distances greater than or equal to 10.8 miles from the central hospital. Therefore, certain changes are needed in those VARIABLES used to obtain service times for calls received from these distances. These changes are explained below.

$$V20 = K648/V14 + V22 * K3/K25 + X65 *K3/K25 + FN15 + K1$$

This provides the time in minutes to a real call at a distance greater than or equal to 10.8 miles plus the time at the scene, plus the return time to the hospital. It is used to compute times needed by satellite ambulances when helicopters are introduced into the system and assumes that the ambulance will travel at a constant speed of 50 miles per hour to the scene of a call from its answering location.

V30 = K648/V14 + V22 * K3/K25 + X65 * K3/K19 + FN15 + K1

This provides the time in minutes to a real call at a distance greater than or equal to 10.8 miles from the central hospital, plus the delay at the scene, plus the return time to the hospital, plus a one minute delay. It is used to compute the time needed by a centrally located ambulance when helicopters are added to the system and assumes that the ambulance travels at a constant speed of 38 miles per hour to the scene of the call. The assumed speed is the average of the 50 miles per hour assumed beyond 10.8 miles and the mean speed found inside 10.8 miles.

As a final assistance in understanding this model, an example of that part of a three ambulance system which finds the closest ambulance if necessary is provided in Figure 15.

Figure 15 shows transactions entering after the call coordinates and sector have been determined. ASSIGN blocks 1 through 3 assign parameter 10 a value of either one, two, or three corresponding to sectors one through three. The transaction then goes through SAVEX blocks 4, 5, and 6 where X31 through X33 are each set to 5000. Later in the program X31 through X33 will contain the distance from an ambulance to a call. In the event that an ambulance is not available to answer this call, the value 5000 will insure that it does not meet the requirement of being the closest to the call location.

Transactions then go to either COMPARE block 7, 8, or 9 where

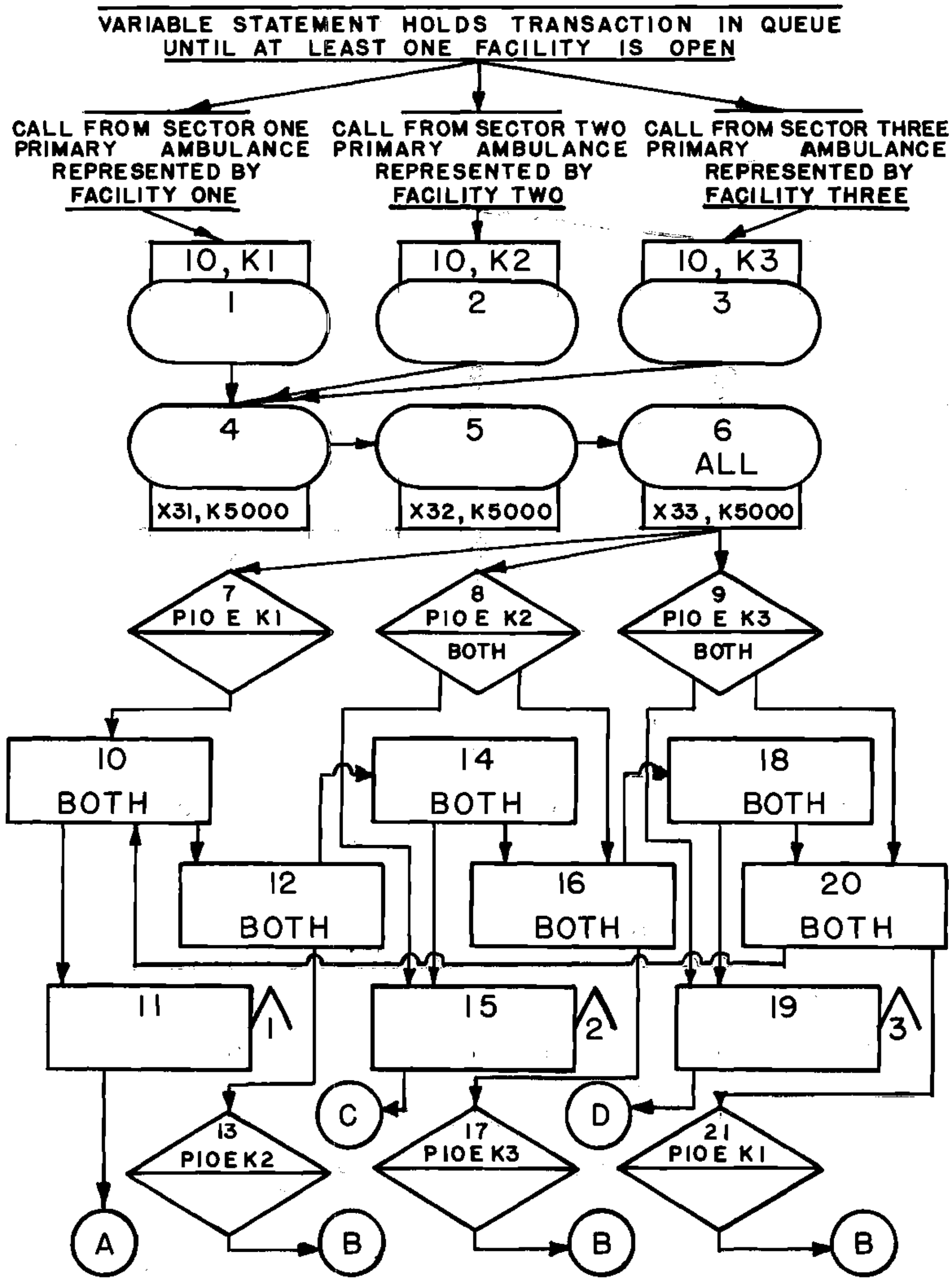


Figure 15. Sample Flow Chart for Priority System.

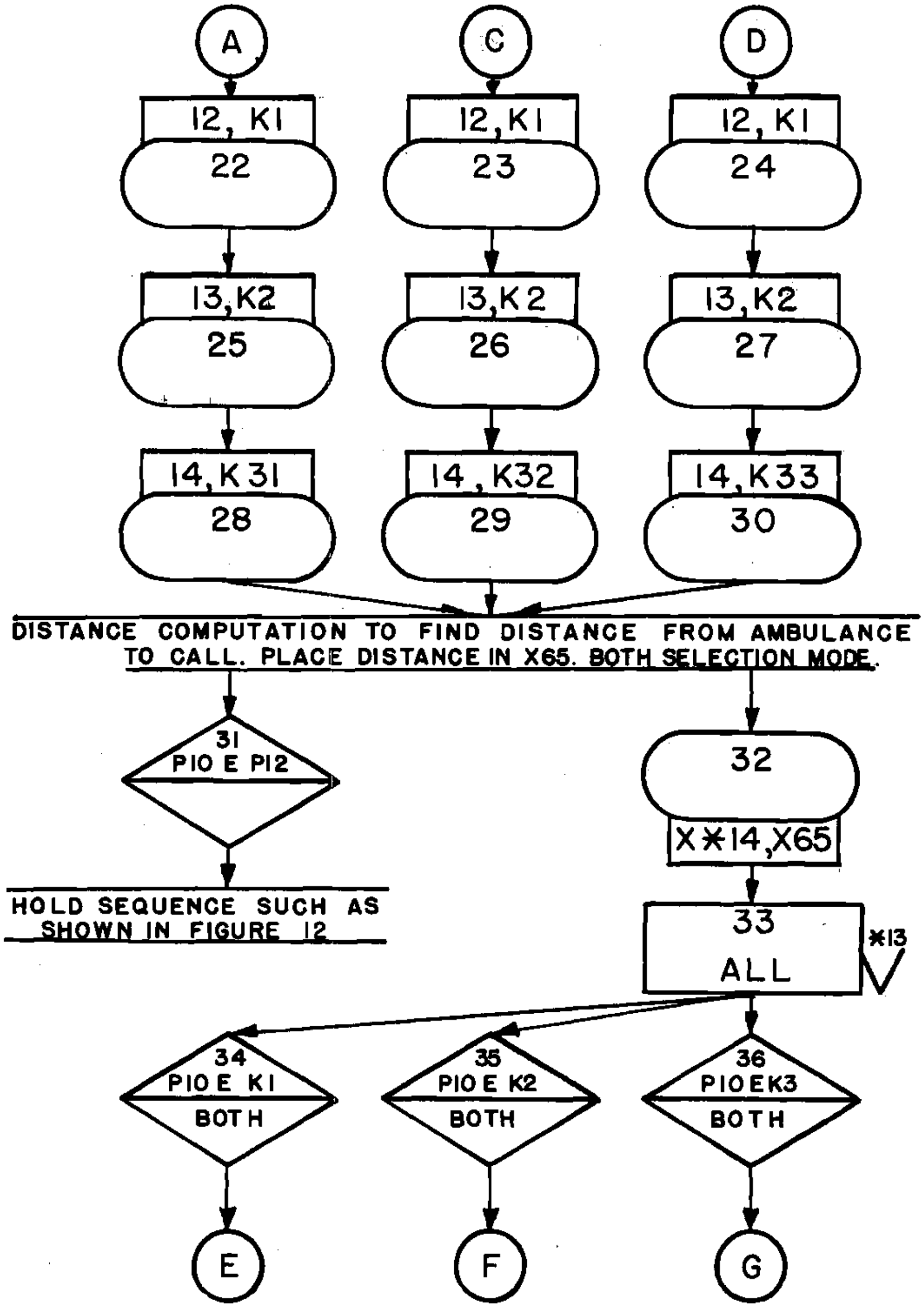


Figure 15 Continued

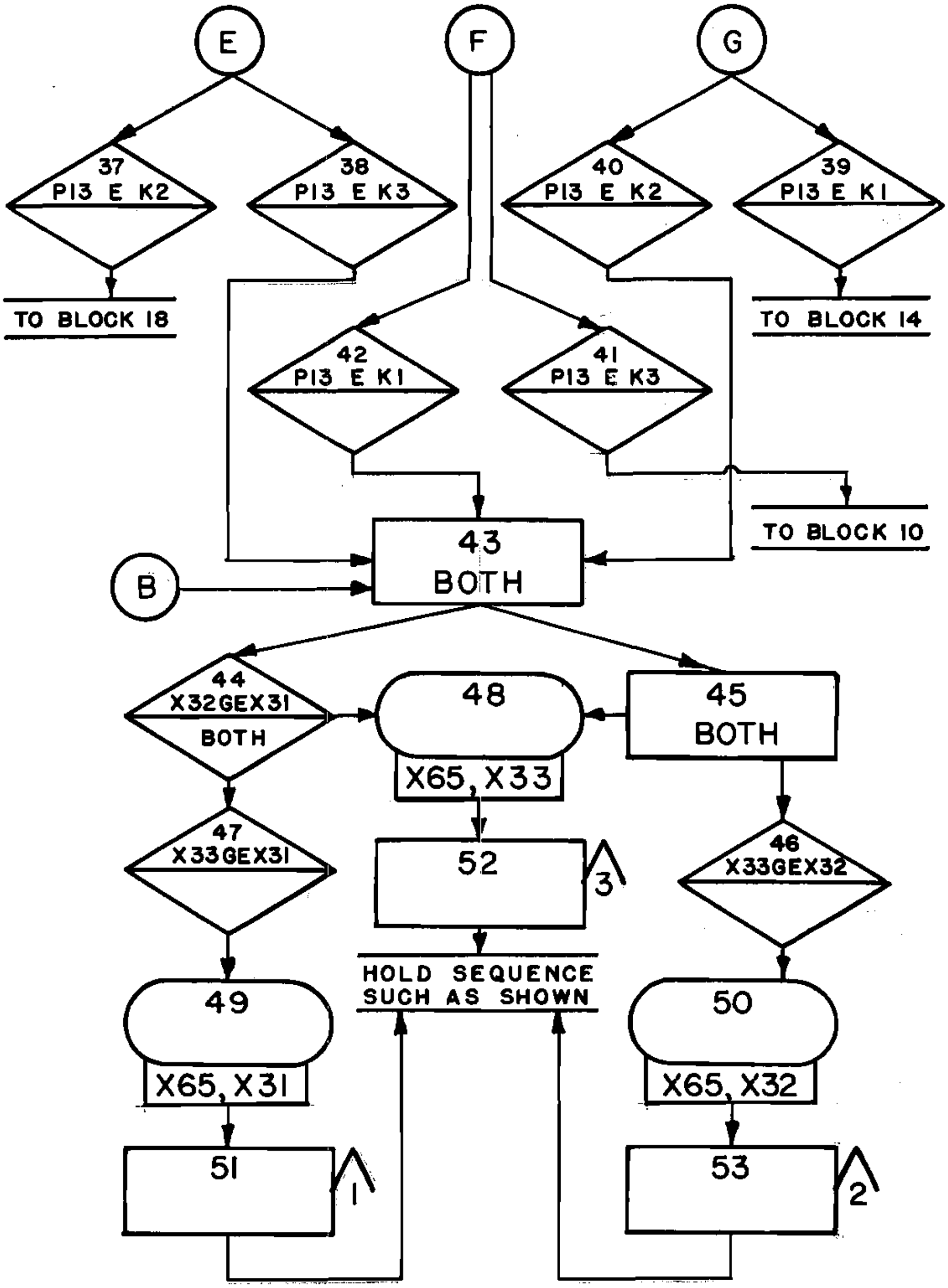


Figure 15 Continued

they are directed first to the facility representing the primary ambulance for the sector from which the call was received. SEIZE blocks 11, 15, and 19 represent the ambulances.

If the primary ambulance is not available, the transaction will attempt to enter the next available facility. Earlier in the program, a VARIABLE statement has insured that at least one facility is open.

COMPARE blocks 13, 17, and 21 serve to prevent the transaction from attempting to enter the same facility twice.

After leaving a SEIZE block the transaction will enter one of the series of three ASSIGN blocks shown in Figure 30. Parameter 12 corresponds to the sector, parameter 13 to the facility, and parameter 14 to the SAVEX location containing the distance from the call to the ambulance. Both parameters 12 and 13 are needed if more than one ambulance is assigned to a sector as will be found in the model for the entire decentralized system with priorities.

After setting parameters 12 through 14, the transaction enters a sequence to compute the distance from the ambulance to the call. This distance is placed in X65.

The transaction then attempts to enter COMPARE block 31. If parameter 10 equals parameter 12 the transaction enters and this means that the ambulance answering the call was the primary ambulance for the sector from which the call was received. Appropriate delays are then found, the service time is computed, and finally the transaction is terminated.

If the transaction can not enter block 31, it indicates that the primary ambulance has not answered the call and therefore the distances between the call and all other available ambulances must be found and that ambulance which is the closest to the call will answer.

To accomplish this, the transaction is routed to SAVEX block 32 where the SAVEX location specified by parameter 14 (X31 - X33) is assigned the distance to the call found in X65. From there the transaction is sent to RELEASE block 33 where the ambulance just tested is released.

From the RELEASE block, the transaction will enter the sequence of COMPARE blocks 34 through 42 where it will either again be routed through the SEIZE blocks until all have been tested, or after all are tested it will go to ADVANCE block 43.

Before entering block 43, therefore, all ambulances have been tested, and if the primary ambulance was not available all other ambulances that were available will have the distance from them to the call placed in either X31, X32, or X33. Again, X31 through X33 correspond to facilities one through three.

Blocks 43 through 47 compare the three distances, and the transaction will then go to either block 48, 49, or 50 depending on which distance is the shortest. This smallest distance is then placed in X65, and the facility corresponding to the closest ambulance is seized. Appropriate delays are then found, the service time is computed, and finally the transaction is terminated.

Though the sample flow chart is for only three ambulances, it illustrates how an expanded system could be used for the nine ambulances simulated in the decentralized system with priorities and helicopters.

Results of the Decentralized System with Priorities and Helicopters

As has been stated, the first model simulated assumed nine ambulances in the system. With nine ambulances, 89.35 percent of the calls received did not spend time in a queue. Average time in a queue for all entries was 1.63 minutes. Average service time was 45.27 minutes. Average service time plus queue time was 46.85 minutes. Ambulance utilization was 43.25 percent.

With eight ambulances in the system, 80.81 percent of the calls received did not spend time in a queue. Average time in a queue for all entries was 3.56 minutes. Average service time was 46.08 minutes. Average service time plus queue time was 49.64 minutes. Ambulance utilization was 47.78 percent.

It can be seen that a small increase in service time occurred when one ambulance was removed from the system. In fact the first replication of the simulation resulted in a smaller service time for the eight ambulance system. This requires an explanation.

As ambulances are removed from the system, the closest ambulance to a call is more often required to answer this call. As an example that ambulance having primary responsibility for a satellite sector may have just returned to service at the scene of the central hospital when a second call is received in its sector. At the same time, an ambulance from the central sector may have just been released at the scene of a false call and may be closer to the new call than is the primary ambulance. Nevertheless, the primary ambulance would answer the call. As the number of ambulances assigned primary responsibility is increased, this example will occur more frequently.

With seven ambulances in the system, 58.71 percent of the calls received did not spend time in a queue. Average time spent in the queue for all entries was 10.07 minutes. Average service time was 48.21 minutes. Average service time plus queue time was 58.28 minutes. Ambulance utilization was 58.81 percent. As a result of the time spent in a queue, it was determined that eight ambulances was the minimum number needed in the system to provide acceptable service, and a decrease beyond seven ambulances was not simulated.

Helicopter ambulances were next added to the model. With nine ambulances and four helicopters in the system, 98.05 percent of the calls received did not spend any time in a queue. Average time in the queue for all entries was 0.13 minutes. Average service time was 39.98 minutes. Average service time plus queue time was 40.01 minutes. Ambulance utilization was 24.39 percent. Helicopter utilization was 25.38 percent and 29.52 percent of the calls received used helicopter evacuation.

The cost of the helicopter ambulance dictates that a high utilization figure be obtained for this vehicle. Since four helicopters in the system resulted in a utilization figure of only 17.02 and 8.98 percent for helicopters three and four, the number of helicopters in the system was immediately reduced to two.

With two helicopters and nine ambulances in the system, 97.59 percent of the calls received did not spend any time in a queue. Average time in the queue for all entries was 0.14 minutes. Average service time was 39.93 minutes. Average service time plus queue time was 40.07 minutes. Ambulance utilization was 28.96 percent. Helicopter utilization was 32.72 percent and 21.43 percent of the calls received used helicopter evacuation.

Since helicopter utilization remained low in a two helicopter system, a system with nine ambulances and one helicopter was next simulated. In this system, 95.86 percent of the calls received did not spend time in a queue. Average time in the queue for all entries was 0.44 minutes. Average service time was 40.27 minutes. Average service time plus queue time was 40.71 minutes. Ambulance utilization was 34.05 percent. Helicopter utilization was 36.38 percent and 11.55 percent of the calls received used helicopter evacuation.

To see what effect a helicopter would have on ground ambulances in the system, the next model simulated contained eight ambulances and one helicopter. In this system 88.91 percent of the calls received did not spend time in a queue. Average time in the queue for all entries was 1.35 minutes. Average service time was 42.39 minutes. Average service time plus queue time was 43.74 minutes. Ambulance utilization was 35.94 percent. Helicopter utilization was 35.94 percent and 11.55 percent of the calls received used helicopter evacuation.

With seven ambulances and one helicopter in the system, 71.00 percent of the calls received did not spend time in a queue. Average time in the queue for all entries was 10.67 minutes. Average service time was 43.88 minutes. Average service time plus queue time was 54.55 minutes. Ambulance utilization was 44.29 percent. Helicopter utilization was 35.58 percent and 11.43 percent of the calls received used helicopter evacuation.

As a result of the time spent in a queue, it was determined that eight ambulances was the minimum number needed in a system with one helicopter to provide acceptable service. A further decrease in the number of ambulances was not simulated, but a second helicopter was added.

With seven ambulances and two helicopters in the system, 81.12 percent of the calls received did not spend time in a queue. Average time in the queue for all entries was 3.72 minutes. Average service time was 43.92 minutes. Average service time plus queue time was 47.64 minutes. Ambulance utilization was 38.94 percent. Helicopter utilization was 31.24 percent and 21.43 percent of the calls received used helicopter evacuation.

<u>Other Comments on the Simulations</u>

Table 12 summarizes the results of all the simulations performed. The program portions of the computer output for each of the models discussed in this chapter may be found in Appendices A through D.

Table 12. Summary of the Simulation Results

VEHICLES IN THE SYSTEM	EXPANDED CENTRALIZED			DECEN. W/QUE. IN SECTOR	DECENTRALIZED WITH PRIORITIES AND HELICOPTERS								
AMBULANCES	7	8	9	6	7	8	9	9	9	9	8	7	7
HELICOPTERS	0	0	0	0	0	0	0	4	2	1	1	1	2
% OF CALLS USING HELICOPTER	–	–	–	–	–	–	–	29.52	21.43	11.55	11.55	11.43	21.43
HELICOPTER UTILIZATION	–	–	–	–	–	–	–	25.38	32.72	36.38	35.94	35.58	31.24
PERCENT ZERO QUEUE	45	75	99	1.28	58.71	80.81	89.35	98.04	97.59	95.86	88.91	71.00	81.12
AMBULANCE UTILIZATION	61.82	53.11	49.80	100.0	58.81	47.78	43.25	24.39	28.96	34.05	39.21	44.29	38.94
AVERAGE SERVICE TIME	50.11	48.81	49.47	41.00	48.21	46.08	45.27	39.98	39.93	40.27	42.39	43.88	43.92
AVERAGE SERVICE PLUS QUEUE TIME	69.39	52.36	49.67	2609	58.28	49.64	46.85	40.01	40.07	40.71	43.74	54.55	47.64
ALL ENTRY QUEUE TIME	19.28	3.55	0.20	2568	10.07	3.56	1.63	0.13	0.14	0.44	1.35	10.67	3.72

CHAPTER IV

LIMITATIONS, CONCLUSIONS AND RECOMMENDATIONS

Limitations

The models used in this thesis are limited by the following assumptions made during their development. It was first assumed that traffic density remained constant throughout the length of the simulations. Rush hours and their associated delays in ground vehicle movement due to congestion were not included in the systems discussed. The relationship between the ambulance call rate and a particular hour or day was also assumed to be insignificant.

Only the call distribution obtained from Grady Memorial Hospital was used. In addition, the helicopter models answered only those calls received from beyond a fixed distance from the hospital. The positioning of ground ambulances in these models was such that only those calls in which the satellite ambulance moved away from the hospital used helicopter evacuation. Those calls received from locations between the satellite ambulances and the hospital were taken directly to the hospital.

Conclusions

Grady Memorial Hospital

Two specific conclusions are immediately apparent. Although Grady Memorial Hospital ambulances may be called from anywhere in Fulton or DeKalb counties, very few, less than one percent, of calls can be expected from a distance of greater than ten miles from the hospital. Private ambulances will answer most calls at a greater distance and because of this, a helicopter ambulance actually operating from Grady would probably contribute very little to the present system.

The system of decentralization proposed by Grady, that is stationing one ambulance at South Fulton Hospital with a responsibility for South Fulton County is likewise quickly seen to be impractical. South Fulton Hospital is nearly eight miles from Grady if rectangular measurement is used, and the sample of calls used found less than 0.5 percent of calls coming from the area of responsibility given the ambulance stationed at South Fulton Hospital.

The Computer Simulations

The results of the validation model for Grady Memorial Hospital satisfied the requirements of the Kolmogorov-Smirnov test for the distributions of time between calls, service time, and distance distribution. The behavior of the simulation model produced no significant reason for rejection of the model as an acceptable representation of an ambulance system.

The model for a decentralized system with queues in sectors demonstrated that the decentralized stationing of ambulances can reduce the service time. Though the model was inefficient in terms of the number of ambulances needed to avoid queuing in the system, it did show that the ambulance stationing and sector assignments being used would provide a workable model.

The simulations of a decentralized system with priorities indicates that a system in which the closest ambulance to a call always answers may be more efficient than the system that was simulated. Decentralized positioning of the ambulances will, however, remain necessary to allow this new system to work.

The small increase in service time found as helicopters are decreased from four to one in the decentralized system with priorities indicates that one helicopter would provide the most cost effective addition to the system simulated. The decrease in the number of calls using the helicopter for evacuation when only one helicopter is available, coupled with the small increase in service time would indicate that a larger area of responsibility would provide for more effective use of the helicopter ambulance. This conclusion is further supported by the low helicopter utilization figure obtained when only one helicopter is used.

A comparison of the service plus queue times obtained in the simulations of a nine ambulance decentralized system with priorities, and the system with two helicopters and seven ambulances, indicates that the addition of ground ambulances to a system may provide a reduction in time equal to that achieved by the addition of helicopters, and at much less cost.

Finally, it can be concluded that when estimating the cost of adding helicopters to a system, more consideration must be given to the effect the helicopter will have on the ground ambulances in that system.

Recommendations for Future Research

The following recommendations are offered for future research.

1. In addition to the simulations completed in this thesis, several other variations are possible using the model proposed and should be investigated. These include:

a. Varying the multiplication factor of three used in the simulation, thus increasing or decreasing area coverage.

b. Addition of one or more additional hospitals in the area being studied.

c. Vary sector assignments or boundaries and the number of sectors.

d. Provide additional ambulances equal in cost to the cost of a helicopter to determine if this system would be advantageous.

e. Simulate satellite helicopters.

f. Vary satellite ambulance and helipad locations.

2. The possibility of some systematic method of determining the optimal location of sector boundaries warrants further examination. In addition to the number of calls in a sector, the size of that sector and distance distribution within the sector must be considered. The determination of the optimal locations for satellite ambulances and helipads will necessarily be included in a more detailed examination of sector boundaries.

3. A two-step-method of helicopter evacuation has been simulated. A comparison with a direct helicopter evacuation system could provide a measure of the time available at an actual call scene for selection of a landing site and transportation of the patient directly to the helicopter. Further investigation in this area is recommended.

Other Recommendations

The delay in returning an ambulance to service after reaching Grady Memorial Hospital is excessive when a deceased person is involved. Currently, the ambulance and attendant involved may be required to proceed to the Fulton County Morgue and remain there while administrative details such as the inventory of personal items are accomplished. It is recommended that once a patient has been pronounced dead, the body be transferred to the morgue by means less critical than an ambulance.

APPENDIX A

THE VALIDATION MODEL

```
-LOC--NAME----------X------Y------Z------SEL---NBA---NB9---MEAN--MOD---REMARKS---F---

     JOB
 5    FUNCTION    RN1   D104                                                   NE    .1
.01020400457.02041424433.03061415442.04082382439.05102433427.06122400460
.07143416442.08163394454.09184397457.10204397460.11224415448.12245403460
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 7    FUNCTION    RN1   D115                                                   NX    +0
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.50459340460.51376292412.52294289415.53211283412.54128322451.55046304433
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.6    .915  .7    1.2   .75   1.38  .8    1.6   .84   1.83  .88   2.12
.9    2.3   .92   2.52  .94   2.81  .95   2.99  .96   3.2   .97   3.5
.98   3.9   .99   4.6   .995  5.3   .998  6.2   .999  7     .9997 8
 2    FUNCTION    RN1   D5                                              **SELECT
.151  206   .327  207   .523  208   .672  209   1     210
 15   FUNCTION    RN1   D10                                                DELAY
.057  20    .134  19    .2    18    .267  17    .334  16    .4    15
.7    5     .8    4     .9    3     1     2
 5    VARIABLE    X108/K1000-K400                                        EW DIST
 6    VARIABLE    K0-X109                                               NEGEWPOS
 7    VARIABLE    X108(K1000-K400                                        NS DIST
 8    VARIABLE    K0-X111                                               NEGNSPOS
 9    VARIABLE    X109/K3+X110/K3+X111/K3+X112/K3                       TOT DIST
 10   VARIABLE    X113*K12/V14+FN15+V16+K1
 16   FUNCTION    RN1   C6                                                RETURN
0     0     .18   20    .23   50    .34   80    .52   140   1     510
 16   VARIABLE    FN16/K10
 14   FUNCTION    RN1   C19                                             SPEED100
0     600   .0087 560   .0262 500   .0525 450   .0875 410   .1313 390
.1839 370   .2452 350   .3153 330   .3942 310   .4818 290   .5694 260
.6570 280   .7359 210   .8060 190   .8673 170   .9199 150   .9637 120
1     100
 14   VARIABLE    FN14/K10
 200  ORIGINATE                     202         24    FN30
 201  ORIGINATE                     202         25    FN30
 202  TABULATE    1                 205
 1    TABLE       IA    4     5     36
 205  ADVANCE                 FN    2
 206  SAVEX       108   FN6         211
 207  SAVEX       108   FN7         211
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208  SAVEX      108   FN8               211
209  SAVEX      108   FN9               211
210  SAVEX      108   FN10              211
211  SAVEX      109   V5          BOTH  212   215
212  COMPARE    X109  L     K0          213
213  SAVEX      110   V6                214
214  SAVEX      109   K0                216
215  SAVEX      110   K0                216
216  SAVEX      111   V7          BOTH  217   219
217  COMPARE    X111  L     K0          218
218  SAVEX      112   V8                220
219  SAVEX      112   K0                221
220  SAVEX      111   K0                221
221  SAVEX      113   V9                222
222  SAVEX      114   V10               223
223  PRINT      113   114               500
500  TERMINATE  R
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APPENDIX B

THE EXPANDED CENTRALIZED SYSTEEM MODEL

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LOC  NAME         X      Y      Z      SEL   NBA   NBB   MEAN  MOD   REMARKS   F

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.6      .915   .7     1.2    .75    1.38   .8     1.6    .84    1.83   .88    2.12
.9      2.3    .92    2.52   .94    2.81   .95    2.99   .96    3.2    .97    3.5
.98     3.9    .99    4.6    .995   5.3    .998   6.2    .999   7      .9997  8
 2     FUNCTION      RN1    D5                                          **SELECT
.151    421    .327   422    .523   423    .672   424    1      425
 15    FUNCTION      RN1    D10                                            DELAY
.067    20     .134   19     .2     18     .267   17     .334   16     .4     15
.7      5      .8     4      .9     3      1      2
 16    FUNCTION      RN1    C6                                            RETURN
0       0      .13    20     .23    50     .34    80     .52    140    1      510
 16    VARIABLE      FN16/K10
 14    VARIABLE      FN14/K10
 14    FUNCTION      RN1    C19                                         SPEED100
0       600    .0087  560    .0262  500    .0525  450    .0875  410    .1313  390
.1839   370    .2452  350    .3153  330    .3942  310    .4818  290    .5694  260
.6570   280    .7359  210    .8060  190    .8673  170    .9199  150    .9637  120
1       100
 17    FUNCTION      RN1    D10                                          * DELAY
.111    20     .223   19     .334   18     .445   17     .556   16     .667   15
.92     5      .947   4      .974   3      1      2
 41    FUNCTION      RN1    D3
.03     102    .12    103    1      104
 42    FUNCTION      RN1    D3
.03     125    .12    126    1      127
 43    FUNCTION      RN1    D3
.03     148    .12    149    1      150
 44    FUNCTION      RN1    D3
.03     171    .12    172    1      173
 45    FUNCTION      RN1    D3
.03     194    .12    195    1      196
 46    FUNCTION      RN1    D3
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.03   217    .12    219   1     219
 47   FUNCTION      RN1   D3
.03   240    .12    241   1     242
 48   FUNCTION      RN1   D3
.03   263    .12    264   1     265
 49   FUNCTION      RN1   D3
.03   286    .12    287   1     288
 50   FUNCTION      RN1   D3
.03   309    .12    310   1     311
 1    VARIABLE   X98/K1000-X11/K1000      POS OR NEG EW DIST AMB TO CALL
 2    VARIABLE   K0-X12                   EW DIST MADE POS IF NEG
 3    VARIABLE   X98(K1000-X11(K1000      POS OR NEG NS DIST AMB TO CALL
 4    VARIABLE   K0-X13                   NS DIST MADE POS IF NEG
 5    VARIABLE   X13+X12                * TOTAL DISTANCE AMBULANCE TO CALL (X14)
 6    VARIABLE   X98/K1000-K400           POS OR NEG EW DIST HOSP TO CALL
 7    VARIABLE   K0-X15                   EW DIST MADE POS IF NEG
 8    VARIABLE   X98(K1000-K400           POS OR NEG NS DIST HOSP TO CALL
 9    VARIABLE   K0-X16                   NS DIST MADE POS IF NEG
 10   VARIABLE   X15+X16                * TOTAL DISTANCE HOSPITAL TO CALL (X17)
 19   VARIABLE   X14-V20                  DIST AMB TO CALL LESS THAN 10.8 MILES
 20   VARIABLE   X17-K108                 DIST HOSP TO CALL GREATER THAN 10.8 MI
 21   VARIABLE   X14*K6/V14+K5            TIME TO ARRIVE AT AND SERVICE FALSE C
 22   VARIABLE   X14*K6/V14+FN17+K1       ARRIVE AND SERVE TIME ASSISTANCE ONLY
 23   VARIABLE   X14*K6/V14+FN15+K1+X17*K6/V14  REAL CALL DIST LESS THAN 10.8 7
 24   VARIABLE   V20*K6/V25+K646/V14+V19*K6/V14+FN15+K1  REAL CALL DIST A) 10.8
 25   VARIABLE   X17*K3/V14               HALF TIME RTN CALL TO HOSPITAL
 501  ORIGINATE  1     1                  502        1
 502  ASSIGN     2     K4                 503
 503  SAVEX      99    K80080             504
 504  SAVEX      99+   K80080             505
 505  LOOP       2                        504    506
 506  SAVEX      1     X99                507
 507  SAVEX      2     X99                508
 508  SAVEX      3     X99                509
 509  SAVEX      4     X99                510
 510  SAVEX      5     X99                511
 511  SAVEX      6     X99                512
 512  SAVEX      7     X99                513
 513  SAVEX      8     X99                514
 514  SAVEX      9     X99                515
 515  SAVEX      10    X99                500
 427  ORIGINATE  2                        444         24     FN30
 428  ORIGINATE  2                        444         25     FN30
 444  QUEUE      1                 ALL    401    408
 1    QTABLE     1     0      30   50
 401  SEIZE      1                        411
 402  SEIZE      2                        412
 403  SEIZE      3                        413
 404  SEIZE      4                        414
 405  SEIZE      5                        415
 406  SEIZE      6                        416
 407  SEIZE      7                        417
 408  SEIZE      8                        418
 411  ASSIGN     14    K1                 426
 412  ASSIGN     14    K2                 426
 413  ASSIGN     14    K3                 426
 414  ASSIGN     14    K4                 426
 415  ASSIGN     14    K5                 426
 416  ASSIGN     14    K6                 426
 417  ASSIGN     14    K7                 426
 418  ASSIGN     14    K8                 426
 426  ADVANCE                      FN     2
 421  SAVEX      98    FN6                11
 422  SAVEX      98    FN7                11
 423  SAVEX      98    FN8                11
 424  SAVEX      98    FN9                11
 425  SAVEX      98    FN10               11
 11   SAVEX      11    X*14               12
 12   SAVEX      12    V1          BOTH   13     14
 13   COMPARE    X12   L      K0          15
 14   SAVEX      13    V3          BOTH   16     17
 15   SAVEX      12    V2                 14
 16   COMPARE    X13   L      K0          18
 17   SAVEX      14    V5                 19
 18   SAVEX      13    V4                 17
 19   SAVEX      15    V6          BOTH   20     21
 20   COMPARE    X15   L      K0          22
```

21	SAVEX	16	V8		BOTH	23	24	
22	SAVEX	15	V7			21		
23	COMPARE	X16	L	K0		25		
25	SAVEX	16	V9			24		
24	SAVEX	17	V10		ALL	1	8	
1	COMPARE	P14	E	K1	BOTH	100	101	
2	COMPARE	P14	E	K2	BOTH	123	124	
3	COMPARE	P14	E	K3	BOTH	146	147	
4	COMPARE	P14	E	K4	BOTH	169	170	
5	COMPARE	P14	E	K5	BOTH	192	193	
6	COMPARE	P14	E	K6	BOTH	215	215	
7	COMPARE	P14	E	K7	BOTH	238	239	
8	COMPARE	P14	E	K8	BOTH	261	262	
100	COMPARE	X17	GE	K108		105		
101	ADVANCE				FN	41		
102	ASSIGN	1	V21			105		
103	ASSIGN	1	V22			106		
104	ASSIGN	1	V23			107		
105	ASSIGN	1	V24			107		
106	SAVEX	1	X98			110		
107	HOLD	11				109		*1
108	TABULATE	11				114		
109	TABULATE	11				111		
110	HOLD	11				108		*1
111	ASSIGN	1	V16			113		
112	ADVANCE				BOTH	701	500	
113	HOLD	21				115		*1
114	RELEASE	1				118		
115	SAVEX	1	X99			117		
116	LOOP	1				112	711	
117	RELEASE	1				500		
118	ASSIGN	1	V25		BOTH	721	731	
721	COMPARE	P1	L	K1		122		
731	ADVANCE				BOTH	119	500	
119	GATE	NU1				120		
701	GATE	NU1				120		
120	HOLD	31				116		1
121	GATE	NU1				122		
711	ADVANCE				BOTH	121	500	
122	SAVEX	1	X99			500		
123	COMPARE	X17	GE	K108		128		
124	ADVANCE				FN	42		
125	ASSIGN	2	V21			129		
126	ASSIGN	2	V22			129		
127	ASSIGN	2	V23			130		
128	ASSIGN	2	V24			130		
129	SAVEX	2	X98			133		
130	HOLD	12				132		*2
131	TABULATE	12				137		
132	TABULATE	12				134		
133	HOLD	12				131		*2
134	ASSIGN	2	V16			136		
135	ADVANCE				BOTH	702	500	
136	HOLD	22				138		*2
137	RELEASE	2				141		
138	SAVEX	2	X99			140		
139	LOOP	2				135	712	
140	RELEASE	2				500		
141	ASSIGN	2	V25		BOTH	722	732	
722	COMPARE	P2	L	K1		145		
732	ADVANCE				BOTH	142	500	
142	GATE	NU2				143		
702	GATE	NU2				143		
143	HOLD	32				139		1
144	GATE	NU2				145		
712	ADVANCE				BOTH	144	500	
145	SAVEX	2	X99			500		
146	COMPARE	X17	GE	K108		151		
147	ADVANCE				FN	43		
148	ASSIGN	3	V21			152		
149	ASSIGN	3	V22			152		
150	ASSIGN	3	V23			153		
151	ASSIGN	3	V24			153		
152	SAVEX	3	X98			156		
153	HOLD	13				155		*3
154	TABULATE	13				160		
155	TABULATE	13				157		
156	HOLD	13				154		*3

157	ASSIGN	3	V16			159		
158	ADVANCE				BOTH	703	500	
159	HOLD	23				161		*3
160	RELEASE	3				164		
161	SAVEX	3	X99			163		
162	LOOP	3				158	713	
163	RELEASE	3				500		
164	ASSIGN	3	V25		BOTH	723	733	
723	COMPARE	P3	L	K1		168		
733	ADVANCE				BOTH	165	500	
165	GATE	NU3				166		
703	GATE	NU3				166		
166	HOLD	33				162		1
167	GATE	NU3				168		
713	ADVANCE				BOTH	167	500	
168	SAVEX	3	X99			500		
169	COMPARE	X17	GE	K108		174		
170	ADVANCE				FN	44		
171	ASSIGN	4	V21			175		
172	ASSIGN	4	V22			175		
173	ASSIGN	4	V23			176		
174	ASSIGN	4	V24			176		
175	SAVEX	4	X98			179		
176	HOLD	14				178		*4
177	TABULATE	14				183		
178	TABULATE	14				180		
179	HOLD	14				177		*4
180	ASSIGN	4	V16			182		
181	ADVANCE				BOTH	704	500	
182	HOLD	24				184		*4
183	RELEASE	4				187		
184	SAVEX	4	X99			186		
185	LOOP	4				181	714	
186	RELEASE	4				500		
187	ASSIGN	4	V25		BOTH	724	734	
724	COMPARE	P4	L	K1		191		
734	ADVANCE				BOTH	188	500	
188	GATE	NU4				189		
189	HOLD	34				185		1
704	GATE	NU4				189		
190	GATE	NU4				191		
714	ADVANCE				BOTH	190	500	
191	SAVEX	4	X99			500		
192	COMPARE	X17	GE	K108		197		
193	ADVANCE				FN	45		
194	ASSIGN	5	V21			198		
195	ASSIGN	5	V22			198		
196	ASSIGN	5	V23			199		
197	ASSIGN	5	V24			199		
198	SAVEX	5	X98			202		
199	HOLD	15				201		*5
200	TABULATE	15				206		
201	TABULATE	15				203		
202	HOLD	15				200		*5
203	ASSIGN	5	V16			205		
204	ADVANCE				BOTH	705	500	
205	HOLD	25				207		*5
206	RELEASE	5				210		
207	SAVEX	5	X99			209		
208	LOOP	5				204	715	
209	RELEASE	5				500		
210	ASSIGN	5	V25		BOTH	725	735	
725	COMPARE	P5	L	K1		214		
735	ADVANCE				BOTH	211	500	
211	GATE	NU5				212		
705	GATE	NU5				212		
212	HOLD	35				208		1
213	GATE	NU5				214		
715	ADVANCE				BOTH	213	500	
214	SAVEX	5	X99			500		
215	COMPARE	X17	GE	K108		220		
216	ADVANCE				FN	46		
217	ASSIGN	6	V21			221		
218	ASSIGN	6	V22			221		
219	ASSIGN	6	V23			222		
220	ASSIGN	6	V24			222		
221	SAVEX	6	X98			225		
222	HOLD	16				224		*6

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223  TABULATE  16                        229
224  TABULATE  16                        226
225  HOLD      16                        223         *6
226  ASSIGN    6     V16                 228
227  ADVANCE                       BOTH  706   500
228  HOLD      26                        230         *6
229  RELEASE   6                         233
230  SAVEX     6     X99                 232
231  LOOP      6                         227   716
232  RELEASE   6                         500
233  ASSIGN    6     V25           BOTH  726   736

726  COMPARE   P6    L     K1            237
736  ADVANCE                       BOTH  234   500
234  GATE      NU6                       235
706  GATE      NU6                       235
235  HOLD      36                        231         1
236  GATE      NU6                       237
716  ADVANCE                       BOTH  236   500
237  SAVEX     6     X99                 500
11   TABLE     M1    30    30      50
12   TABLE     M1    30    30      50
13   TABLE     M1    30    30      50
14   TABLE     M1    30    30      50
15   TABLE     M1    30    30      50
16   TABLE     M1    30    30      50
238  COMPARE   X17   GE    K108          243
239  ADVANCE                       FN    47
240  ASSIGN    7     V21                 244
241  ASSIGN    7     V22                 244
242  ASSIGN    7     V23                 245
243  ASSIGN    7     V24                 245
244  SAVEX     7     X98                 248
245  HOLD      17                        247         *7
246  TABULATE  17                        252
247  TABULATE  17                        249
248  HOLD      17                        246         *7
249  ASSIGN    7     V16                 251
250  ADVANCE                       BOTH  707   500
251  HOLD      27                        253         *7
252  RELEASE   7                         255
253  SAVEX     7     X99                 255
254  LOOP      7                         250   717
255  RELEASE   7                         500
256  ASSIGN    7     V25           BOTH  727   737
727  COMPARE   P7    L     K1            260
737  ADVANCE                       BOTH  257   500
257  GATE      NU7                       258
707  GATE      NU7                       258
258  HOLD      37                        254         1
259  GATE      NU7                       260
717  ADVANCE                       BOTH  259   500
260  SAVEX     7     X99                 500
17   TABLE     M1    30    30      50
261  COMPARE   X17   GE    K108          266
262  ADVANCE                       FN    48
263  ASSIGN    8     V21                 267
264  ASSIGN    8     V22                 267
265  ASSIGN    8     V23                 268
266  ASSIGN    8     V24                 268
267  SAVEX     8     X98                 271
268  HOLD      18                        270         *8
269  TABULATE  18                        275
270  TABULATE  18                        272
271  HOLD      18                        269         *8
272  ASSIGN    8     V16                 274
273  ADVANCE                       BOTH  708   500
274  HOLD      28                        276         *8
275  RELEASE   8                         279

276  SAVEX     8     X99                 278
277  LOOP      8                         273   718
278  RELEASE   8                         500
279  ASSIGN    8     V25           BOTH  728   738
728  COMPARE   P8    L     K1            283
738  ADVANCE                       BOTH  280   500
280  GATE      NU8                       281
708  GATE      NU8                       281
281  HOLD      38                        277         1
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 292  GATE         NU8                             283
 718  ADVANCE                               BOTH  292    500
 253  SAVEX        8      X99                      500
 19   TABLE        M1     30     30      50
 500  TERMINATE    R
      START        200
       CLEAR
 501  ORIGINATE    1      1                        502           1

****WARNING- THIS CARD OVERLAYS A PRIOR CARD WITH THE SAME BLOCK NUMBER

 427  ORIGINATE    2                               444           24     FN30

****WARNING- THIS CARD OVERLAYS A PRIOR CARD WITH THE SAME BLOCK NUMBER

 428  ORIGINATE    2                               444           25     FN30

****WARNING- THIS CARD OVERLAYS A PRIOR CARD WITH THE SAME BLOCK NUMBER

 444  QUEUE        1                        ALL    401    409

****WARNING- THIS CARD OVERLAYS A PRIOR CARD WITH THE SAME BLOCK NUMBER

 409  SEIZE        9                               419
 419  ASSIGN       14     K9                       426
 24   SAVEX        17     V10               ALL    1      9

****WARNING- THIS CARD OVERLAYS A PRIOR CARD WITH THE SAME BLOCK NUMBER

 9    COMPARE      P14    E      K9         BOTH   284    285
 284  COMPARE      X17    GE     K108              289
 285  ADVANCE                               FN     49
 286  ASSIGN       9      V21                      290
 287  ASSIGN       9      V22                      290
 288  ASSIGN       9      V23                      291
 289  ASSIGN       9      V24                      291
 290  SAVEX        9      X98                      294
 291  HOLD         19                              293           *9
 292  TABULATE     19                              298
 293  TABULATE     19                              295
 294  HOLD         19                              292           *9
 295  ASSIGN       9      V16                      297
 296  ADVANCE                               BOTH   709    500
 297  HOLD         29                              299           *9
 298  RELEASE      9                               302
 299  SAVEX        9      X99                      301
 300  LOOP         9                               296    719
 301  RELEASE      9                               500
 302  ASSIGN       9      V25               BOTH   729    739
 729  COMPARE      P9     L      K1                306
 739  ADVANCE                               BOTH   303    500
 303  GATE         NU9                             304
 709  GATE         NU9                             304
 304  HOLD         39                              300           1
 305  GATE         NU9                             306
 719  ADVANCE                               BOTH   305    500
 306  SAVEX        9      X99                      500
 19   TABLE        M1     30     30      50
      START        200
```

APPENDIX C

THE DECENTRALIZED MODEL WITH QUEUES IN SECTORS

```
LOC  NAME          X      Y      Z      SEL    NBA    NBB    MEAN   MOD    REMARKS    F

     JOB           017123665275
 1   FUNCTION      RN1    D104                                                NE     +1
.01020400457.02041424433.03061415442.04082382439.05102433427.06122400460
.07143418442.08163394454.09184397457.10204397460.11224415448.12245403460
.13265379442.14286421442.15306397463.16327427439.17347403463.18367392448
.19388421445.20408397466.21429421448.22449376445.23469436433.24490397469
.25510385457.26531388460.27551385460.28571397472.29592442436.30612433445
.31633451427.32653373451.33673451430.34694403478.35714439445.36735376463
.37755394481.38776442445.39796391484.40816367460.41837457439.42857418481
.43878466436.44898442460.45918358453.46939409496.47959361469.48980415493
.50000466445.51020424490.52041358472.53061400514.54082442472.55102460457
.56122358475.57143406511.58163478445.59184412511.60204424502.61224424511
.62245484451.63265400538.64286412526.65306403535.66327388535.67347487460
.68357406541.69388354511.70408490457.71429427523.72449424526.73469388541
.74490465487.75510430523.76531364517.77551424541.78571436529.79592448517
.80612424544.81633376544.82653472496.83674400574.84694403577.85714409583
.86735415583.87755400593.88776460547.89541424585.90561340553.91582400622
.92602460568.93112352583.94133400634.94643532505.95663292538.96684436616
.96939508547.97450403655.97959292553.98214556508.99235412655.99490436649
.99745460537 1.000042467
 2   FUNCTION      RN1    D115                                                NW     +0
.00917346403.01835349406.02752361418.03670364421.04587343403.05505352412
.06422355415.07339340403.08257367430.09174355421.10092367433.11009343409
.11927334400.12844346415.13762349419.14679364433.15596331400.16514343412
.17431367436.18349352421.19266355427.20184352424.21101361433.22018358430
.22936349424.23853334409.24771337412.25688439335.26606328403.27523343418
.28440353433.29358349427.30275346427.31193352433.32110322403.33028334415
.33945337418.34862346430.35780343427.36697359442.37615343430.38532331418
.39450319406.40367346436.41284355445.42202331421.43119343436.44037346439
.44954346442.45872325421.46789340445.47706316421.48624295400.49541334442
.50459340460.51376292412.52294289415.53211283412.54128322451.55046304433
.55963265403.56881324466.57798322463.58716265409.59633304445.60551298442
.61468265415.62385295445.63303253409.64220304460.65138250406.66055292448
.66972322484.67890247427.68807277460.69725271454.70642220406.71560256442
.72477292478.73394285475.74312283478.75229307502.76147199403.77064280484
.77982247454.78899280487.79587274484.80505196409.81422256475.82339223442
.83257232454.84174235457.85092226451.86009241466.86927187415.87844232460
.88303259490.89220196430.90138208442.91055159405.91972226469.92431250499
.92661271526.93119259517.93578259520.93807220484.94725244514.95642241514
.95560226508.97477235517.97706217502.98624196484.99541196490.99771181478
1.000196496
 3   FUNCTION      RN1    D127                                                SW     +1
.00620367376.01639346397.02459358385.03279367373.04098352388.04918397343
.05738376364.06557355385.07377346394.08197370370.09016361379.09836367370
.10656361376.11475388349.12295364373.13115382355.13934397340.14754358376
.15574376358.16393382352.17213349395.18033379355.18852337394.19672398343
.20492355373.21311352376.22131331397.22951334394.23771367361.24590361367
.25409385343.26230394334.27049343379.27869334388.28689379343.29508361361
.30328355367.31148367355.31967331388.32787361358.33607331385.34426373343
.35246367349.36066370345.36885361355.37705316397.38525370343.39344391322
.40164364349.40984313397.41803344361.42623391319.43443319388.44262331376
.45082334373.45902331373.46721382322.47541376328.48361367337.49180313388
.50000379322.50820385316.51639334367.52459361340.53279361337.54098313379

.54918373319.55738328364.56557292397.57377307382.58197328361.59016313373
.59836292394.60656364322.61475400286.62295328352.63115331349.63934376304
.64754349328.65574325352.66393340337.67213280394.68033298376.68852343331
.69672352322.70492325346.71312285385.72131340331.72951367298.73771322343
.74590364298.75410334328.76229361298.77049340316.77869289367.78689310346
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.89344295307.90164340259.90984322277.91803298301.92623352241.93033328262
.93443268301.93853232331.94672319235.95082295256.95902268277.96721292244
.97541211313.98361232289.98566325193.98771340175.99590226283.99795172331
1.0000256244
 4   FUNCTION      RN1    D103                                                SE     +1
.01020451406.02041442415.03061445412.04082412355.05102406349.06122451394
.07143433376.08163442418.09184457397.10204457406.11225448385.12245460397
.13265415352.14286445392.15306454412.16327427361.17347466403.18367442373
.19388454335.20408463406.21429424352.22449457385.23469442367.24490475400
.25510451375.26531433358.27551460409.28571475403.29592478403.30612472409
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.62245415304.63265405295.64286484373.65306502409.66327502415.67347418301
.68367472355.69388481351.70408508412.71429490367.72449496373.73469517415
.74490466334.75510502430.76531508376.77551424292.78571460328.79592481346
.80612538397.81633514354.82653538427.83673445274.84694484313.85714544427
.86735544433.87755406229.88776568391.89796541442.90816532457.91837550442
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1.0000570430
 5     FUNCTION     RN1    D202                                              CENTRAL1
.00495397400.00990400397.01485400403.01980403400.02475394400.02970397403
.03465400406.03960403403.04455403397.04951391400.05446406397.05941394403
.06436400391.06931403394.07426409400.07921400388.08416391403.08911394406
.09406400412.09901409403.10369403409.10891406405.11386388397.11881400385
.12376385400.12871388403.13366394409.13861397412.14356400415.14851412397
.15347382400.15842388406.16337394412.16832409391.17327385397.17822391409
.18317403415.18812400382.19307418400.19802391389.20297382397.20792382403
.21287385405.21782412409.22277391412.22772388409.23267403382.23762418403
.24257406385.24752397379.25247382394.25743382406.26238412388.26733409385
.27228406382.27723421403.28218412412.28713385409.29208394418.29703400373
.30198376397.30693385398.31188388415.31683394421.32178424397.32673421394
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.68812382427.69307430385.69802427382.70297424421.70792400445.71287391436
.71782442397.72277439394.72723406361.73267415430.73762355400.74257364391
.74753364409.75248436412.75743439409.76238358406.76733367415.77228379373

.77723376376.78218421427.78713400448.79208412364.79703403355.80198445397
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 6     FUNCTION     RN1    D202                                              CENTRAL1
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.15347382400.15842388405.16337394412.16832409391.17327385397.17822391409
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.92574400346.93069355409.93564364418.94059373373.94554373430.95050421436
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.95545364382.96040445391.96535397349.97030388358.97525379367.98020385442
.98515376433.99010424433.995054154421.0000430376
 10   FUNCTION   RN1   D5
.151  51    .327  52    .523  53    .672  54    1     55
 17   FUNCTION   RN1   D10                                        * DELAY
.111  20    .223  19    .334  18    .445  17    .556  16    .667  15
.92   5     .947  4     .974  3     1     2
 15   FUNCTION   RN1   C6                                           RETURN
0     0     .18   20    .23   50    .34   80    .52   140   1     510
 15   FUNCTION   RN1   D10                                           DELAY
.067  20    .134  19    .2    18    .267  17    .334  16    .4    15
.7    5     .8    4     .9    3     1     2
 14   FUNCTION   RN1   C19                                        SPEED100
0     600   .0087 560   .0262 500   .0525 450   .0875 410   .1313 390
.1839 370   .2452 350   .3153 330   .3942 310   .4818 290   .5694 260
.6570 280   .7359 210   .8060 190   .8673 170   .9199 150   .9637 120

1     100
 30   FUNCTION   RN1   C24
 0    0     .1    .104  .2    .222  .3    .355  .4    .509  .5    .69
.6    .915  .7    1.2   .75   1.38  .8    1.6   .84   1.83  .88   2.12
.9    2.3   .92   2.52  .94   2.81  .95   2.99  .96   3.2   .97   3.5
.96   3.9   .99   4.6   .995  5.3   .998  6.2   .999  7     .9997 8
 41   FUNCTION   RN1   D3
.03   314   .12   315   1     316
 42   FUNCTION   RN1   D3
.03   324   .12   325   1     326
 43   FUNCTION   RN1   D3
.03   334   .12   335   1     336
 44   FUNCTION   RN1   D3
.03   344   .12   345   1     346
 45   FUNCTION   RN1   D3
.03   354   .12   355   1     356
 46   FUNCTION   RN1   D3
.03   364   .12   365   1     366
 1    VARIABLE   X100/K1000-K400
 2    VARIABLE   K0-X66
 3    VARIABLE   X100(K1000-K400
 4    VARIABLE   K0-X8
 5    VARIABLE   X66+X7+X8+X9
 6    VARIABLE   X12/K1000
 7    VARIABLE   X12(K1000
 8    VARIABLE   X100/K1000-X13
 9    VARIABLE   K0-X15
 10   VARIABLE   X100(K1000-X14
 11   VARIABLE   K0-X17
 12   VARIABLE   X16+X17+X18+X15
 13   VARIABLE   K648/V14
 14   VARIABLE   FN14/K10
 16   VARIABLE   FN16/K10
 21   VARIABLE   X10-K108
 22   VARIABLE   X19*K12/V14+K5                              FALSE CALL
 23   VARIABLE   X19*K12/V14+FN17+K3                         AID NO TRANS
 24   VARIABLE   X19*K6/V14+X10*K6/V14+FN15+K1               REAL LESS 108
 25   VARIABLE   X19*K3/K25+FN15+K1+V21*K3/K25+X11           REAL GREATER
 35   VARIABLE   K648/V14+FN16                               RTN SAT + DELA
 501  ORIGINATE  1     1           502     1
 502  ASSIGN     2     K4          503
 503  SAVEX      1     K83696      504                       NE
 504  SAVEX      1+    K83698      505
 505  LOOP       2                 504     506               COORD
 506  ASSIGN     2     K4          507
 507  SAVEX      4     K93274      508
 508  SAVEX      4+    K93271      509                       SATELITE
 509  LOOP       2                 508     510               COORD
 510  ASSIGN     2     K4          511
 511  SAVEX      3     K69270      512                       SW
 512  SAVEX      3+    K69269      513                       SATELITE
 513  LOOP       2                 512     514               COORD
 514  ASSIGN     2     K4          515
 515  SAVEX      2     K65089      516                       NW
 516  SAVEX      2+    K65086      517                       SATELITE
 517  LOOP       2                 516     518               COORD
 518  ASSIGN     2     K4          519

 519  SAVEX      5     K80080      520
 520  SAVEX      5+    K80080      521                       HOSPITAL
 521  LOOP       2                 520     522               COORD
```

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522  SAVEX      6     X5                      523
523  PRINT      1     6                       500
10   ORIGINATE  2                             14            24    FN30
11   ORIGINATE  2                             14            25    FN30
14   ADVANCE                           FN     10
51   QUEUE      1                             61                              NE WAIT
1    QTABLE     1     0     30         50
52   QUEUE      2                             62                              NW WAIT
2    QTABLE     1     0     30         50
53   QUEUE      3                             63                              SW WAIT
3    QTABLE     1     0     30         50
54   QUEUE      4                             64                              SE WAIT
4    QTABLE     1     0     30         50
55   QUEUE      5                      BOTH   65     56
5    QTABLE     1     0     30         50
61   SEIZE      1                             31                        NE AMB O
62   SEIZE      2                             32                        NW AMB O
63   SEIZE      3                             33                        SW AMB O
64   SEIZE      4                             34
65   SEIZE      5                             35                        CU AMB O
66   SEIZE      6                             36                        CT AB O
31   SPLIT                                    310    41
32   SPLIT                                    320    42
33   SPLIT                                    330    43
34   SPLIT                                    340    44
35   SPLIT                                    350    45
36   SPLIT                                    360    46
41   ASSIGN     8     K1                      100
42   ASSIGN     8     K2                      100
43   ASSIGN     8     K3                      100
44   ASSIGN     8     K4                      100
45   ASSIGN     8     K5                      100
46   ASSIGN     8     K6                      100
100  SAVEX      100   FN*8                    101
101  SAVEX      66    V1               BOTH   102    106
102  COMPARE    X66   L     K0                103
103  SAVEX      7     V2                      104
104  SAVEX      66    K0                      105
105  SAVEX      7     K0                      106
106  SAVEX      8     V3               BOTH   107    110
107  COMPARE    X8    L     K0                108
108  SAVEX      9     V4                      109
109  SAVEX      8     K0                      111
110  SAVEX      9     K0                      111
111  SAVEX      10    V5               BOTH   112    113
112  COMPARE    X10   LE    K54               114
113  SAVEX      11    V13                     115
114  SAVEX      11    K0                      115
115  SAVEX      12    X*8                     116
116  SAVEX      13    V6                      117
117  SAVEX      14    V7                      201
201  SAVEX      15    V8               BOTH   202    205
202  COMPARE    X15   L     K0                203
203  SAVEX      16    V9                      204
204  SAVEX      15    K0                      206
205  SAVEX      16    K0                      206
206  SAVEX      17    V10              BOTH   207    210
207  COMPARE    X17   L     K0                208
208  SAVEX      18    V11                     209
209  SAVEX      17    K0                      211
210  SAVEX      18    K0                      211
211  SAVEX      19    V12              ALL    221    226
221  GATE       M310                          310
222  GATE       M320                          320
223  GATE       M330                          330
224  GATE       M340                          340
225  GATE       M350                          350
226  GATE       M360                          360
310  ASSEMBLE   2                      BOTH   311    312
320  ASSEMBLE   2                      BOTH   321    322
330  ASSEMBLE   2                      BOTH   331    332
340  ASSEMBLE   2                      BOTH   341    342
350  ASSEMBLE   2                      BOTH   351    352
360  ASSEMBLE   2                      BOTH   361    362
311  COMPARE    X10   GE    K108              313
312  ADVANCE                           FN     41
313  ASSIGN     1     V25                     401
314  ASSIGN     1     V22                     317
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315   ASSIGN     1      V23                  317
316   ASSIGN     1      V24                  401
401   HOLD       11                          402         *1
402   TABULATE   11                          403
403   ASSIGN     1      V35                  404
404   HOLD       21                          91          *1
317   HOLD       11                          318         *1
318   TABULATE   11                          91
91    RELEASE    1                           500
321   COMPARE    X10    GE    K108           323
322   ADVANCE                          FN    42
323   ASSIGN     2      V25                  405
324   ASSIGN     2      V22                  327
325   ASSIGN     2      V23                  327
326   ASSIGN     2      V24                  405
405   HOLD       12                          406         *2
406   TABULATE   12                          407
407   ASSIGN     2      V35                  408
408   HOLD       22                          92          *2
327   HOLD       12                          328         *2
328   TABULATE   12                          92
92    RELEASE    2                           500
331   COMPARE    X10    GE    K108           333
332   ADVANCE                          FN    43
333   ASSIGN     3      V25                  409
334   ASSIGN     3      V22                  337
335   ASSIGN     3      V23                  337
336   ASSIGN     3      V24                  409
409   HOLD       13                          410         *3
410   TABULATE   13                          411
411   ASSIGN     3      V35                  412
412   HOLD       23                          93          *3
337   HOLD       13                          338         *3

338   TABULATE   13                          93
93    RELEASE    3                           500
341   COMPARE    X10    GE    K108           343
342   ADVANCE                          FN    44
343   ASSIGN     4      V25                  413
344   ASSIGN     4      V22                  347
345   ASSIGN     4      V23                  347
346   ASSIGN     4      V24                  413
413   HOLD       14                          414         *4
414   TABULATE   14                          415
415   ASSIGN     4      V35                  416
416   HOLD       24                          94          *4
347   HOLD       14                          348         *4
348   TABULATE   14                          94
94    RELEASE    4                           500
351   COMPARE    X10    GE    K108           353
352   ADVANCE                          FN    45
353   ASSIGN     5      V25                  417
354   ASSIGN     5      V22                  357
355   ASSIGN     5      V23                  357
356   ASSIGN     5      V24                  417
417   HOLD       15                          418         *5
418   TABULATE   15                          419
419   ASSIGN     5      FN16                 420
420   HOLD       25                          95          *5
357   HOLD       15                          358         *5
358   TABULATE   15                          95
95    RELEASE    5                           500
361   COMPARE    X10    GE    K108           363
362   ADVANCE                          FN    46
363   ASSIGN     6      V25                  421
364   ASSIGN     6      V22                  367
365   ASSIGN     6      V23                  367
366   ASSIGN     6      V24                  421
421   HOLD       16                          422         *6
422   TABULATE   16                          423
423   ASSIGN     6      FN16                 424
424   HOLD       26                          96          *6
367   HOLD       16                          368         *6
368   TABULATE   16                          96
96    RELEASE    6                           500
11    TABLE      M1     30    30       50
12    TABLE      M1     30    30       50
13    TABLE      M1     30    30       50
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14    TABLE        M1    30    30    50
15    TABLE        M1    30    30    50
16    TABLE        M1    30    30    50
500   TERMINATE    R
      START        200
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APPENDIX D

THE DECENTRALIZED MODEL WITH AMBULANCE PRIORITIES AND HELICOPTERS

```
LOC  NAME          X     Y     Z      SEL   NBA   NBB   MEAN  MOD   REMARKS   F

      JOB          017123665275
 1    FUNCTION     RN1   D104  STATISTICAL COORDINATES FOR NORTHEAST SECTOR
.01020400457.02041424433.03061415442.04082382439.05102433427.06122400460
.07143418442.08163394454.09184397457.10204397460.11224415458.12245403460
.13265379442.14286421442.15306397463.16327427439.17347403463.18367382448
.19388421445.20408357465.21429421448.22449370445.23469436433.24490397469
.25510385457.26531358460.27551385460.28571397472.29592442436.30612433445
.31633451427.32653373451.33673451430.34694403479.35714439445.36735376463
.37755394461.38776442445.39796391474.40816367460.41837457439.42857418481
.43878466436.44898442460.45918354463.46939409496.47959361469.48980415493
.50000466445.51020424490.52041358472.53061400514.54082442472.55102460457
.56122358475.57143406511.58163470445.59184412511.60204424502.61224424511
.62245484451.63265400538.64286412526.65306403535.66327388535.67347487460
.68367406541.69388364511.70408490457.71429427523.72449424526.73469388541
.74490466487.75510430523.76531364517.77551424561.78571436529.79592448517
.80612424544.81633376544.82653472496.83674400574.84694403577.85714409583
.86735415583.87755400598.88776460547.89541424586.90561340553.91582400622
.92602450568.93112352583.94133400634.94643532505.95653292538.96684436616
.96939508547.97450403655.97959292553.98214556569.99235412655.99490436649
.997454600371,0000424676
 2    FUNCTION     RN1   D115  STATISTICAL COORDINATES FOR WESTHEAST SECTOR
.00917346403.01835349400.02752361418.03670364421.04587343403.05505352412
.06422355415.07339340403.08257367430.09174355421.10092367433.11009343409
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.17431367436.18349352421.19266355427.20184352424.21101361473.22018358430
.22936349424.23853334409.24771337412.25688439336.26605328403.27523343418
.28440358433.29358349427.30275346427.31193352433.32110322403.33028334415
.33945337418.34862346430.35780343427.36697358447.37615343430.38532331418
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.55963265413.56881323466.57798322463.58716268469.59633304465.60551298442
.61468265415.62385295445.63303253409.64220304460.65137250406.66055292448
.66972322464.67890247427.68807277460.69725271454.70642220496.71560256442
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.77982247454.78899250437.79817274424.80505196452.81422256475.82339223442
.83257232454.84174235457.85092226451.86009241466.86927187415.87844232460
.88303259490.89220196430.90138208442.91055169466.91972226469.92431250499
.92651271526.93119259517.93578259520.93807220474.94725244514.95642241514
.96560226508.97477235517.97706217502.98624196484.99541196470.99771181478
1.0000196496
 3    FUNCTION     SN1   D127  STATISTICAL COORDINATESSOUTHWESTHEAST SECTOR
.00820367376.01639346397.02459350385.03279367373.04098352346.04918347343
.05738376364.06557355385.07377346394.08197370370.09016361379.09836367370
.10656361376.11475368349.12295364373.13115382355.13934397340.14754358376
.15574376358.16393362352.17213349335.18033370355.18852337394.19672388343
.20492355373.21311352376.22131331397.22951334394.23771367361.24590361367
.25409385343.26230394334.27049343379.27869334366.28689379343.29508361361
.30328355367.31148367355.31967331398.32787361393.33607331305.34426373343
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.50000379322.50820385316.51639334367.52459361340.53279361337.54098313379
.54918373319.55738328364.56557292397.57377307382.58197328391.59016313373
.59836292394.60656364322.61475400246.62295328352.63115331349.63934376304
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.97541211313.98361232289.98566325193.98771340175.99590226283.99795172331
1.0000256244
 4    FUNCTION     FN1   D113  STATISTICAL COORDINATESSOUTHEASTHEAST SECTOR
.01020451406.02041442415.03061445412.04082412355.05102406349.06122451394
.07143433376.08163442418.09184457397.10204457466.11225448325.12245460397
.13265415352.14286445382.15306454412.16327427361.17347466403.18367442373
.19388454365.20408463406.21429424352.22449457355.23469442367.24490475400
.25510451376.26531433358.27551466409.28571475463.29592478403.30612472469
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1.0000670430
 5    FUNCTION    RN1   D202  STATISTICAL COORDINATESCENTRAL SECTOR
.00495397400.00990400397.01485400403.01980403400.02475394400.02970397403
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.12376385400.12871388403.13366394409.13861397412.14356400415.14851412397
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.36139427397.36634412418.37129409421.37624406424.38119370400.38614388418
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.95545364362.96040445391.96535397349.97030388358.97525379367.98020385442
.98515376433.99010424433.99505415421.0000430376
 17   FUNCTION    RN1   D10   DELAY AT SCENE OF ASSISTANCE ONLY CALL
.111  20    .223  19    .334  18    .445  17    .556  16    .667  15
.92   5     .947  4     .974  3     1     2
 10   FUNCTION    RN1   D5    SECTOR SELECTION
.151  7     .327  8     .523  9     .672  10    1     11
 16   FUNCTION    RN1   C6    DELAY RETURNING TO SERVICE FROM HOSPITAL X TSN
0     0     .18   20    .23   50    .34   80    .52   140   1     510
 15   FUNCTION    RN1   D10   DELAY AT CALL SCENE FOR REAL CALL
.067  20    .134  19    .2    18    .267  17    .334  16    .4    15
.7    5     .8    4     .9    3     1     2
 14   FUNCTION    RN1   C19   AMBULANCE SPEED WITHIN 10.8 MILES X TEN
0     600   .0087 560   .0262 500   .0525 450   .0875 410   .1313 390
.1839 370   .2452 350   .3153 330   .3942 310   .4819 290   .5694 260
.6570 280   .7359 210   .8060 190   .8673 170   .9199 150   .9637 120
1     100
 30   FUNCTION    RN1   C24   EXPONENTIAL FOR INTERARRIVAL TIME
 0    0     .1    .104  .2    .222  .3    .355  .4    .509  .5    .69
.6    .915  .7    1.2   .75   1.38  .8    1.6   .84   1.83  .88   2.12
.9    2.3   .92   2.52  .94   2.81  .95   2.99  .96   3.2   .97   3.5
.98   3.9   .99   4.6   .995  5.3   .998  6.2   .999  7     .9997 8
 41   FUNCTION    RN1   D3
.03   339   .12   340   1     341
 42   FUNCTION    RN1   D3
.03   344   .12   345   1     346
 43   FUNCTION    RN1   D3
.03   349   .12   350   1     351
 44   FUNCTION    RN1   D3
.03   354   .12   355   1     356
 45   FUNCTION    RN1   D3
.03   359   .12   360   1     361
 46   FUNCTION    RN1   D3
.03   364   .12   365   1     366
 47   FUNCTION    RN1   D3
.03   369   .12   370   1     371
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48    FUNCTION     FN1     D3
.03   374   .12    375     1       376
49    FUNCTION     FN1     D3
.03   379   .12    380     1       381
1     VARIABLE     K16*F5+K8*F4+K4*F3+K2*F2+F1     FACILITY 1 THRU 5  STATUS
2     VARIABLE     K8*F6+K4*F7+K2*F8+F9            FACILITY 6 THRU 9  STATUS
3     VARIABLE     X100/K1000-X*11/K1000           EW DIST CALL TO HELIPAD
4     VARIABLE     K0-X60  GIVE POS SIGN TO X60 IF NEGATIVE
5     VARIABLE     X100(K1000-X*11(K1000           NS DIST CALL TO HELIPAD
6     VARIABLE     K0-X61  GIVE POS SIGN TO X61 IF NEGATIVE
7     VARIABLE     X60+X61                         TOTAL DISTANCE
8     VARIABLE     X100/K1000-K400                 EW DIST CALL TO HOSPITAL
9     VARIABLE     X100(K1000-K400                 NS DIST CALL TO HOSPITAL
10    VARIABLE     X100/K1000-X*13/K1000           EW DIST CALL TO AMBULANCE
11    VARIABLE     X100(K1000-X*13(K1000           NS DIST CALL TO AMBULANCE
12    VARIABLE     K15   REMOVES ALL HELICOPTERS FROM THE SYSTEM
13    VARIABLE     X66/K1000-X*15/K1000            EW DIST HELIPAD TO SATELLITE
14    VARIABLE     FN14/K10  SPEED IN MILES PER HOUR LESS THAN 10.8 MILES
15    VARIABLE     X66(K1000-X*15(K1000            NS DIST HELIPAD TO SATELLITE
16    VARIABLE     FN16/K10  DELAY AT HOSPITAL AFTER RETURN BEFORE RELEASE
17    VARIABLE     X65*K6/V14+K5                   SERVICE TIME FALSE CALL
18    VARIABLE     X65*K6/V14+FN17+K1              SERVICE TIME ASSISTANCE ONLY CAL
19    VARIABLE     X65*K6/V14+FN15+K1+X64*K6/V14 REAL CALL DIST LESS THAN 10.8
20    VARIABLE     V22*K6/K25+K648/V14+V23*K6/V14+FN15+K1    REAL GREATER THAN 108
21    VARIABLE     X64*K3/V14  HALF TIME RETURN TO HOSPITAL FROM OTHER CALL
22    VARIABLE     X64-K108 DIST HOSP TO CALL GREATER THAN 10.8 MILES
23    VARIABLE     X65-V22 DIST AMBULANCE TO CALL LESS THAN 10.8 MILES
24    VARIABLE     X62*K3/K25+X65*K3/K25+FN15+K6 TIME HELIPAD TO CALL LCN
25    VARIABLE     X67-K108 DIST GREATER THAN 10.8 HELIPAD TO CENTRAL
26    VARIABLE     X67*K3/K10  HALF TIME HELIPAD TO SATELLITE
27    VARIABLE     V25*K3/K10+K324/V14 HALF TIME HELIPAD TO CENTRAL
28    VARIABLE     K324/V14 HALF TIME HOSPITAL TO SATELLITE
29    VARIABLE     X69*K3/V14  HALF TIME RETURN TO SATELLITE FROM OTHER CALL
30    VARIABLE     X100/K1000-X*15/K1000           EW DIST CALL TO SATELLITE
31    VARIABLE     X100(K1000-X*15(K1000           NS DIST CALL TO SATELLITE
501   ORIGINATE    1     1               502          1
502   ASSIGN       2     K4              503
503   SAVEX        21    K80080          504
504   SAVEX        21+   K80080          505
505   LOOP         2                     504    506
506   SAVEX        1     X21             507
507   SAVEX        2     X21             508
508   SAVEX        3     X21             509
509   ASSIGN       2     K4              510
510   SAVEX        24    K82698          511
511   SAVEX        24+   K82698          512
512   LOOP         2                     511    513
513   SAVEX        4     X24             514
514   ASSIGN       2     K4              515
515   SAVEX        25    K92274          516
516   SAVEX        25+   K92271          517
517   LOOP         2                     516    518
518   SAVEX        5     X25             519
519   SAVEX        6     X25             520
520   ASSIGN       2     K4              521
521   SAVEX        27    K69270          522
522   SAVEX        27+   K69269          523
523   LOOP         2                     522    524
524   SAVEX        7     X27             525
525   ASSIGN       2     K4              526
526   SAVEX        28    K60089          527
527   SAVEX        28+   K60086          528
528   LOOP         2                     527    529
529   SAVEX        8     X28             530
530   SAVEX        9     X28             531
531   ASSIGN       2     K4              532
532   SAVEX        11    K86917          533
533   SAVEX        11+   K86913          534
534   LOOP         2                     533    535
535   ASSIGN       2     K5              536
536   SAVEX        12    K89413          537
537   SAVEX        12+   K89411          538
538   LOOP         2                     537    539
539   ASSIGN       2     K5              540
540   SAVEX        13    K87721          541
541   SAVEX        13+   K87720          542
542   LOOP         2                     541    543
543   ASSIGN       2     K4              544
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544	SAVEX	14	K60040			545			
545	SAVEX	14+	K60039			546			
546	LOOP	2				545	547		
547	ASSIGN	2	K4			548			
548	SAVEX	15	K59663			549			
549	SAVEX	15+	K59659			550			
550	LOOP	2				549	551		
551	ASSIGN	2	K4			552			
552	SAVEX	16	K39281			553			
553	SAVEX	16+	K39279			554			
554	LOOP	2				553	555		
555	ASSIGN	2	K4			556			
556	SAVEX	17	K65290			557			
557	SAVEX	17+	K65286			558			
558	LOOP	2				557	559		
559	ASSIGN	2	K4			560			
560	SAVEX	18	K61102			561			
561	SAVEX	18+	K61102			562			
562	LOOP	2				561	563		
563	SAVEX	41	K0			564			
564	SAVEX	42	K0			565			
565	SAVEX	43	K0			566			
566	SAVEX	44	K0			500			
1	ORIGINATE	2				3		24	FN30
2	ORIGINATE	2				3		25	FN30
3	QUEUE	1			BOTH	4	5		
1	QTABLE	1	0	30	50				
4	COMPARE	V1	L	K31		6			
5	COMPARE	V2	L	K15		6			
6	ADVANCE				FN	10			
7	ASSIGN	10	K1			12			
8	ASSIGN	10	K2			12			
9	ASSIGN	10	K3			12			
10	ASSIGN	10	K4			12			
11	ASSIGN	10	K5			12			
12	SAVEX	100	FN*10			13			
13	SAVEX	31	K5000			14			
14	SAVEX	32	K5000			15			
15	SAVEX	33	K5000			16			
16	SAVEX	34	K5000			17			
17	SAVEX	35	K5000			18			
18	SAVEX	36	K5000			19			
19	SAVEX	37	K5000			20			
20	SAVEX	38	K5000			21			
21	SAVEX	39	K5000		ALL	22	26		
22	COMPARE	P10	E	K1		27			
23	COMPARE	P10	E	K2		28			
24	COMPARE	P10	E	K3		29			
25	COMPARE	P10	E	K4		30			
26	COMPARE	P10	E	K5		72			
27	ASSIGN	11	K11			31			
28	ASSIGN	11	K17			31			
29	ASSIGN	11	K15			31			
30	ASSIGN	11	K13			31			
31	SAVEX	60	V3		BOTH	32	34		
32	COMPARE	X60	L	K0		33			
33	SAVEX	60	V4			34			
34	SAVEX	61	V5		BOTH	35	37		
35	COMPARE	X61	L	K0		36			
36	SAVEX	61	V6			37			
37	SAVEX	62	V7			38			
38	SAVEX	66	X*11		ALL	39	42		
39	COMPARE	P10	E	K1		43			
40	COMPARE	P10	E	K2		43			
41	COMPARE	P10	E	K3		44			
42	COMPARE	P10	E	K4		44			
43	ASSIGN	11	K15			45			
44	ASSIGN	11	K14			45			
45	SAVEX	60	V3		BOTH	46	48		
46	COMPARE	X60	L	K0		47			
47	SAVEX	60	V4			48			
48	SAVEX	61	V5		BOTH	49	51		
49	COMPARE	X61	L	K0		50			
50	SAVEX	61	V6			51			
51	SAVEX	63	V7		BOTH	52	55		
52	COMPARE	X63	L	X62		53			
53	SAVEX	62	X63			54			
54	SAVEX	66	X*11			55			

55	ADVANCE				ALL	56	59
56	COMPARE	P10	E	K2		60	
57	COMPARE	P10	E	K3		60	
58	COMPARE	P10	E	K1		61	
59	COMPARE	P10	E	K4		61	
60	ASSIGN	11	K10			62	
61	ASSIGN	11	K11			62	
62	SAVEX	60	V3		BOTH	63	65
63	COMPARE	X60	L	K0		64	
64	SAVEX	60	V4			65	
65	SAVEX	61	V5		BOTH	66	68
66	COMPARE	X61	L	K0		67	
67	SAVEX	61	V6			68	
68	SAVEX	63	V7		BOTH	69	72
69	COMPARE	X63	L	X62		70	
70	SAVEX	62	X63			71	
71	SAVEX	66	X+11			72	
72	SAVEX	60	V8		BOTH	73	75
73	COMPARE	X60	L	K0		74	
74	SAVEX	60	V4			75	
75	SAVEX	61	V9		BOTH	76	78
76	COMPARE	X61	L	K0		77	
77	SAVEX	61	V6			78	
78	SAVEX	64	V7		ALL	79	83
79	COMPARE	P10	E	K1		85	
80	COMPARE	P10	E	K2	BOTH	90	95
81	COMPARE	P10	E	K3		97	
82	COMPARE	P10	E	K4	BOTH	102	105
83	COMPARE	P10	E	K5	ALL	108	110
85	ADVANCE				BOTH	86	87
86	SEIZE	4				143	
87	ADVANCE				BOTH	88	89
88	COMPARE	P10	E	K2		260	
89	ADVANCE				BOTH	90	91
90	SEIZE	8				144	
91	ADVANCE				BOTH	92	93
92	SEIZE	9				145	
93	ADVANCE				BOTH	94	96
94	COMPARE	P10	E	K3		260	
95	ADVANCE				BOTH	92	93
96	ADVANCE				BOTH	98	99
97	ADVANCE				BOTH	98	99
98	SEIZE	7				146	
99	ADVANCE				BOTH	100	101
100	COMPARE	P10	E	K4		260	
101	ADVANCE				BOTH	102	104
102	SEIZE	5				147	
103	SEIZE	6				148	
104	ADVANCE				BOTH	103	106
105	ADVANCE				BOTH	103	106
106	ADVANCE				BOTH	107	112
107	COMPARE	P10	E	K5		260	
108	SEIZE	1				149	
109	SEIZE	2				150	
110	ADVANCE				BOTH	115	114
111	ADVANCE				BOTH	109	113
112	ADVANCE				BOTH	108	111
113	ADVANCE				BOTH	115	114
114	ADVANCE				BOTH	116	85
115	SEIZE	3				151	
116	COMPARE	P10	E	K1		260	
117	ASSIGN	13	K4			126	
118	ASSIGN	13	K8			127	
119	ASSIGN	13	K9			128	
120	ASSIGN	13	K7			129	
121	ASSIGN	13	K5			130	
122	ASSIGN	13	K6			131	
123	ASSIGN	13	K1			132	
124	ASSIGN	13	K2			133	
125	ASSIGN	13	K3			134	
126	ASSIGN	14	K34			135	
127	ASSIGN	14	K38			135	
128	ASSIGN	14	K39			135	
129	ASSIGN	14	K37			135	
130	ASSIGN	14	K35			135	
131	ASSIGN	14	K36			135	
132	ASSIGN	14	K31			135	
133	ASSIGN	14	K32			135	

134	ASSIGN	14	K33			135	
135	SAVEX	60	V10		BOTH	136	138
136	COMPARE	X60	L	K0		137	
137	SAVEX	60	V4			138	
138	SAVEX	61	V11		BOTH	139	141
139	COMPARE	X61	L	K0		140	
140	SAVEX	61	V6			141	
141	SAVEX	65	V7		BOTH	142	152
142	COMPARE	P10	E	P12	ALL	154	162
143	ASSIGN	12	K1			117	
144	ASSIGN	12	K2			118	
145	ASSIGN	12	K2			119	
146	ASSIGN	12	K3			120	
147	ASSIGN	12	K4			121	
148	ASSIGN	12	K4			122	
149	ASSIGN	12	K5			123	
150	ASSIGN	12	K5			124	
151	ASSIGN	12	K5			125	
152	SAVEX	*14	X65			153	
153	RELEASE	*13			ALL	172	176
154	COMPARE	P13	E	K1		163	
155	COMPARE	P13	E	K2		164	
156	COMPARE	P13	E	K3		165	
157	COMPARE	P13	E	K4		166	
158	COMPARE	P13	E	K5		167	
159	COMPARE	P13	E	K6		168	
160	COMPARE	P13	E	K7		169	
161	COMPARE	P13	E	K8		170	
162	COMPARE	P13	E	K9		171	
172	COMPARE	P10	E	K1	ALL	177	184
173	COMPARE	P10	E	K2	ALL	185	191
174	COMPARE	P10	E	K3	ALL	192	199
175	COMPARE	P10	E	K4	ALL	200	206
176	COMPARE	P10	E	K5	ALL	207	212
177	COMPARE	P13	E	K1		111	
178	COMPARE	P13	E	K2		113	
179	COMPARE	P13	E	K3		260	
180	COMPARE	P13	E	K4		104	
181	COMPARE	P13	E	K6		112	
182	COMPARE	P13	E	K7		101	
183	COMPARE	P13	E	K8		91	
184	COMPARE	P13	E	K9		97	
185	COMPARE	P13	E	K1		111	
186	COMPARE	P13	E	K2		113	
187	COMPARE	P13	E	K3		114	
188	COMPARE	P13	E	K4		260	
189	COMPARE	P13	E	K5		104	
190	COMPARE	P13	E	K6		112	
191	COMPARE	P13	E	K7		101	
192	COMPARE	P13	E	K1		111	
193	COMPARE	P13	E	K2		113	
194	COMPARE	P13	E	K3		114	
195	COMPARE	P13	E	K4		89	
196	COMPARE	P13	E	K5		104	
197	COMPARE	P13	E	K6		112	
198	COMPARE	P13	E	K8		91	
199	COMPARE	P13	E	K9		260	
200	COMPARE	P13	E	K1		111	
201	COMPARE	P13	E	K2		113	
202	COMPARE	P13	E	K3		114	
203	COMPARE	P13	E	K4		89	
204	COMPARE	P13	E	K7		260	
205	COMPARE	P13	E	K8		91	
206	COMPARE	P13	E	K9		97	
207	COMPARE	P13	E	K4		89	
208	COMPARE	P13	E	K5		104	
209	COMPARE	P13	E	K6		260	
210	COMPARE	P13	E	K7		101	
211	COMPARE	P13	E	K8		91	
212	COMPARE	P13	E	K9		97	
260	ADVANCE				BOTH	261	262
261	COMPARE	X31	GE	X32	BOTH	266	263
262	ADVANCE				BOTH	267	263
263	ADVANCE				BOTH	265	264
264	ADVANCE				BOTH	269	276
265	COMPARE	X34	GE	X33		270	
266	COMPARE	X33	GE	X32	BOTH	272	264

267	COMPARE	X33	GE	X31	BOTH	268	264
268	COMPARE	X34	GE	X31	BOTH	273	276
269	COMPARE	X35	GE	X34		275	
270	ADVANCE				BOTH	271	276
271	COMPARE	X35	GE	X33		274	
272	COMPARE	X34	GE	X32	BOTH	277	276
273	COMPARE	X35	GE	X31	BOTH	278	283
274	ADVANCE				BOTH	281	283
275	ADVANCE				BOTH	279	283
276	ADVANCE				BOTH	280	283
277	COMPARE	X35	GE	X32	BOTH	282	283
278	COMPARE	X36	GE	X31	BOTH	284	285
279	COMPARE	X36	GE	X34	BOTH	286	285
280	COMPARE	X36	GE	X35		287	
281	COMPARE	X36	GE	X33		288	
282	COMPARE	X36	GE	X32		289	
283	ADVANCE				BOTH	292	295
284	COMPARE	X37	GE	X31	BOTH	291	219
285	ADVANCE				BOTH	217	219
286	COMPARE	X37	GE	X34	BOTH	290	219
287	ADVANCE				BOTH	295	285
288	ADVANCE				BOTH	298	285
289	ADVANCE				BOTH	214	285
290	COMPARE	X38	GE	X34	BOTH	291	233
291	COMPARE	X39	GE	X34		223	
292	COMPARE	X37	GE	X36	BOTH	293	219
293	COMPARE	X38	GE	X36	BOTH	294	233
294	COMPARE	X39	GE	X36		225	
295	COMPARE	X37	GE	X35	BOTH	296	219
296	COMPARE	X38	GE	X35	BOTH	297	233
297	COMPARE	X39	GE	X35		228	
298	COMPARE	X37	GE	X33	BOTH	299	219
299	COMPARE	X38	GE	X33	BOTH	213	233
213	COMPARE	X39	GE	X33		232	
214	COMPARE	X37	GE	X32	BOTH	215	219
215	COMPARE	X38	GE	X32	BOTH	216	233
216	COMPARE	X39	GE	X32		239	
217	COMPARE	X38	GE	X37	BOTH	218	233
218	COMPARE	X39	GE	X37		230	
219	ADVANCE				BOTH	220	233
220	COMPARE	X39	GE	X38		237	
221	COMPARE	X38	GE	X31	BOTH	222	233
222	COMPARE	X39	GE	X31		236	
223	SAVEX	65	X34			224	
224	SEIZE	4				166	
225	SAVEX	65	X36			226	
226	SEIZE	6				168	
227	SEIZE	5				167	
228	SAVEX	65	X35			227	
229	SEIZE	7				169	
230	SAVEX	65	X37			229	
231	SEIZE	3				165	
232	SAVEX	65	X33			231	
233	SAVEX	65	X39			234	
234	SEIZE	9				171	
235	SEIZE	1				163	
236	SAVEX	65	X31			235	
237	SAVEX	65	X38			236	
238	SEIZE	8				170	
239	SAVEX	65	X32			240	
240	SEIZE	2				164	
163	ADVANCE					774	
164	ADVANCE					775	
165	ADVANCE					776	
166	ADVANCE					777	
167	ADVANCE					778	
168	ADVANCE					779	
169	ADVANCE					780	
170	ADVANCE					781	
171	ADVANCE					782	
774	ASSIGN	13	K1			300	
775	ASSIGN	13	K2			300	
776	ASSIGN	13	K3			300	
777	ASSIGN	13	K4			301	
778	ASSIGN	13	K5			302	
779	ASSIGN	13	K6			302	
780	ASSIGN	13	K7			303	
781	ASSIGN	13	K8			304	

782	ASSIGN	13	K9			304		
300	ASSIGN	15	K21			305		
301	ASSIGN	15	K24			305		
302	ASSIGN	15	K25			305		
303	ASSIGN	15	K27			305		
304	ASSIGN	15	K28			305		
305	SAVEX	60	V12		BOTH	307	306	
306	SAVEX	61	V15		BOTH	308	311	
307	COMPARE	X60	L	K0		309		
308	COMPARE	X61	L	K0		310		
309	SAVEX	60	V4			306		
310	SAVEX	61	V6			311		
311	SAVEX	67	V7			783		
783	SAVEX	60	V30		BOTH	784	786	
784	COMPARE	X60	L	K0		785		
785	SAVEX	60	V4			786		
786	SAVEX	61	V31		BOTH	787	789	
787	COMPARE	X61	L	K0		788		
788	SAVEX	61	V6			789		
789	SAVEX	69	V7		ALL	312	320	
312	COMPARE	P13	E	K1	BOTH	321	322	
313	COMPARE	P13	E	K2	BOTH	323	324	
314	COMPARE	P13	E	K3	BOTH	325	326	
315	COMPARE	P13	E	K4	BOTH	327	328	
316	COMPARE	P13	E	K5	BOTH	329	330	
317	COMPARE	P13	E	K6	BOTH	331	332	
318	COMPARE	P13	E	K7	BOTH	333	334	
319	COMPARE	P13	E	K8	BOTH	335	336	
320	COMPARE	P13	E	K9	BOTH	337	338	
321	COMPARE	X64	GE	K108	BOTH	343	342	
322	ADVANCE				FN	41		
339	ASSIGN	1	V17			384		
340	ASSIGN	1	V18			388		
341	ASSIGN	1	V19			392		
342	ASSIGN	1	V20			392		
384	SAVEX	1	X100			385		
385	ASSIGN	16	V21			386		
386	HOLD	11				387		*1
387	TABULATE	11				388		
388	RELEASE	1				389		
389	ADVANCE				BOTH	390	395	
390	COMPARE	P16	L	K1		391		
391	SAVEX	1	X21			500		
392	HOLD	11				393		*1
393	TABULATE	11				394		
394	ASSIGN	1	V16			397		
395	SAVEX	1	X21			396		
396	RELEASE	1				500		
397	HOLD	21				398		*1
398	ADVANCE				BOTH	399	500	
399	GATE	U01				400		
400	HOLD	21				401		1
401	LOOP	16				402	391	
402	ADVANCE				BOTH	403	500	
403	GATE	U1				400		
323	COMPARE	X64	GE	K108	BOTH	343	347	
324	ADVANCE				FN	42		
344	ASSIGN	2	V17			404		
345	ASSIGN	2	V18			404		
346	ASSIGN	2	V19			412		
347	ASSIGN	2	V20			412		
404	SAVEX	2	X100			405		
405	ASSIGN	17	V21			406		
406	HOLD	12				407		*2
407	TABULATE	12				408		
408	RELEASE	2				409		
409	ADVANCE				BOTH	410	418	
410	COMPARE	P17	L	K1		411		
411	SAVEX	2	X21			500		
412	HOLD	12				413		*2
413	TABULATE	12				414		
414	ASSIGN	2	V16			415		
415	HOLD	22				416		*2
416	SAVEX	2	X21			417		
417	RELEASE	2				500		
418	ADVANCE				BOTH	419	500	
419	GATE	U02				420		
420	HOLD	22				421		1

421	LOOP	17				422	411	
422	ADVANCE				BOTH	423	500	
423	GATE	FU2				420		
325	COMPARE	X64	GE	K108	BOTH	343	352	
326	ADVANCE				FN	43		
349	ASSIGN	3	V17			424		
350	ASSIGN	3	V18			424		
351	ASSIGN	3	V19			432		
352	ASSIGN	3	V20			432		
424	SAVEX	3	X100			425		
425	ASSIGN	18	V21			426		
426	HOLD	13				427		*3
427	TABULATE	13				428		
428	RELEASE	3				429		
429	ADVANCE				BOTH	430	435	
430	COMPARE	P18	L	K1		431		
431	SAVEX	3	X21			500		
432	HOLD	13				433		*3
433	TABULATE	13				434		
434	ASSIGN	3	V16			435		
435	HOLD	23				436		*3
436	SAVEX	3	X21			437		
437	RELEASE	3				500		
438	ADVANCE				BOTH	439	500	
439	GATE	FU3				440		
440	HOLD	23				441		1
441	LOOP	18				442	431	
442	ADVANCE				BOTH	443	500	
443	GATE	FU3				440		
343	COMPARE	X12	L	K15		670		
327	COMPARE	X64	GE	K108	BOTH	343	357	
328	ADVANCE				FN	44		
354	ASSIGN	4	V17			444		
355	ASSIGN	4	V18			444		
356	ASSIGN	4	V19			458		
357	ASSIGN	4	V20			458		
444	SAVEX	4	X100			445		
445	ASSIGN	19	V29			446		
446	HOLD	14				447		*4
447	TABULATE	14				448		
448	RELEASE	4				449		
449	ADVANCE				BOTH	450	459	
450	COMPARE	P19	L	K1		451		
451	SAVEX	4	X24			500		
452	HOLD	14				453		*4
453	TABULATE	14				454		
454	ASSIGN	4	V16			455		
455	HOLD	24				456		*4
456	SAVEX	4	X21			457		
457	RELEASE	4				348		
348	ADVANCE				BOTH	450	459	
458	ASSIGN	19	V27			452		
459	ADVANCE				BOTH	460	500	
460	GATE	FU4				461		
461	HOLD	24				462		1
462	LOOP	19				463	451	
463	ADVANCE				BOTH	464	500	
464	GATE	FU4				461		
330	ADVANCE				FN	45		
329	COMPARE	X64	GE	K108	BOTH	343	362	
359	ASSIGN	5	V17			465		
360	ASSIGN	5	V18			465		
361	ASSIGN	5	V19			479		
362	ASSIGN	5	V20			479		
465	SAVEX	5	X100			466		
466	ASSIGN	20	V29			467		
467	HOLD	15				468		*5
468	TABULATE	15				469		
469	RELEASE	5				470		
470	ADVANCE				BOTH	471	480	
471	COMPARE	P20	L	K1		472		
472	SAVEX	5	X25			500		
473	HOLD	15				474		*5
474	TABULATE	15				475		
475	ASSIGN	5	V16			476		
476	HOLD	25				477		*5
477	SAVEX	5	X21			478		

478	RELEASE	5				353		
353	ADVANCE				BOTH	471	480	
479	ASSIGN	20	V25			473		
480	ADVANCE				BOTH	481	500	
481	GATE	LU5				482		
482	HOLD	25				483		1
483	LOOP	20				484	47[illegible]	
484	ADVANCE				BOTH	485	500	
485	GATE	LU5				482		
331	COMPARE	X64	GE	K108	BOTH	343	367	
332	ADVANCE				FN	46		
364	ASSIGN	6	V17			486		
365	ASSIGN	6	V18			486		
366	ASSIGN	6	V19			600		
367	ASSIGN	6	V20			600		
486	SAVEX	6	X100			487		
487	ASSIGN	21	V29			488		
488	HOLD	16				489		*6
489	TABULATE	16				490		
490	RELEASE	6				491		
491	ADVANCE				BOTH	492	601	
492	COMPARE	P21	L	K1		493		
493	SAVEX	6	X25			500		
494	HOLD	16				495		*6
495	TABULATE	16				496		
496	ASSIGN	6	V16			497		
497	HOLD	26				498		*6
498	SAVEX	6	X21			499		
499	RELEASE	6				358		
358	ADVANCE				BOTH	492	601	
600	ASSIGN	21	V28			494		
601	ADVANCE				BOTH	602	500	
602	GATE	LU6				603		
603	HOLD	26				604		1
604	LOOP	21				605	493	
605	ADVANCE				BOTH	606	500	
606	GATE	LU6				603		
333	COMPARE	X64	GE	K108	BOTH	343	372	
334	ADVANCE				FN	47		
369	ASSIGN	7	V17			607		
370	ASSIGN	7	V18			607		
371	ASSIGN	7	V19			621		
372	ASSIGN	7	V20			621		
607	SAVEX	7	X100			608		
608	ASSIGN	22	V29			609		
609	HOLD	17				610		*7
610	TABULATE	17				611		
611	RELEASE	7				612		
612	ADVANCE				BOTH	613	622	
613	COMPARE	P22	L	K1		614		
614	SAVEX	7	X27			500		
615	HOLD	17				616		*7
616	TABULATE	17				617		
617	ASSIGN	7	V16			618		
618	HOLD	27				619		*7
619	SAVEX	7	X21			620		
620	RELEASE	7				363		
363	ADVANCE				BOTH	613	622	
621	ASSIGN	22	V28			615		
622	ADVANCE				BOTH	623	500	
623	GATE	LU7				624		
624	HOLD	27				625		1
625	LOOP	22				626	614	
626	ADVANCE				BOTH	627	500	
627	GATE	LU7				624		
335	COMPARE	X64	GE	K108	BOTH	343	377	
336	ADVANCE				FN	48		
374	ASSIGN	8	V17			628		
375	ASSIGN	8	V18			628		
376	ASSIGN	8	V19			642		
377	ASSIGN	8	V20			642		
628	SAVEX	8	X100			629		
629	ASSIGN	23	V29			630		
630	HOLD	18				631		*8
631	TABULATE	18				632		
632	RELEASE	8				633		
633	ADVANCE				BOTH	634	643	
634	COMPARE	P23	L	K1		635		

635	SAVEX	8	X20			500		
636	HOLD	16				637		*8
637	TABULATE	18				638		
638	ASSIGN	8	V16			639		
639	HOLD	26				640		*8
640	SAVEX	8	X21			641		
641	RELEASE	8				368		
368	ADVANCE				BOTH	634	643	
642	ASSIGN	23	V28			636		
643	ADVANCE				BOTH	644	500	
644	GATE	NU8				645		
645	HOLD	28				646		1
646	LOOP	23				647	635	
647	ADVANCE				BOTH	648	500	
648	GATE	NU8				645		
337	COMPARE	X64	GE	K100	BOTH	343	332	
338	ADVANCE				FN	40		
379	ASSIGN	9	V17			649		
350	ASSIGN	9	V18			649		
351	ASSIGN	9	V19			663		
352	ASSIGN	9	V20			663		
649	SAVEX	8	X100			650		
650	ASSIGN	24	V29			651		
651	HOLD	19				652		*9
652	TABULATE	19				653		
653	RELEASE	9				654		
654	ADVANCE				BOTH	655	664	
655	COMPARE	F24	L	K1		656		
656	SAVEX	9	X20			500		
657	HOLD	19				658		*9
658	TABULATE	19				659		
659	ASSIGN	9	V18			660		
660	HOLD	29				661		*9
661	SAVEX	9	X21			662		
662	RELEASE	9				373		
373	ADVANCE				BOTH	655	664	
663	ASSIGN	24	V29			657		
664	ADVANCE				BOTH	665	500	
665	GATE	NU9				666		
666	HOLD	29				667		1
667	LOOP	24				668	656	
668	ADVANCE				BOTH	669	500	
669	GATE	NU9				666		
670	ADVANCE				ALL	671	674	
671	SEIZE	41				675		
672	SEIZE	42				676		
673	SEIZE	43				677		
674	SEIZE	44				678		
675	SAVEX	P1	K1		BOTH	679	680	
676	SAVEX	P1	K2		BOTH	681	682	
677	SAVEX	P1	K3		BOTH	683	684	
678	SAVEX	P1	K4		BOTH	685	686	
679	COMPARE	X41	GE	K6000		687		
680	SAVEX	70	K25			699		
681	COMPARE	X42	GE	K6000		688		
682	SAVEX	70	K25			700		
683	COMPARE	X43	GE	K6000		689		
684	SAVEX	70	K25			701		
685	COMPARE	X44	GE	K6000		690		
686	SAVEX	70	K25			702		
687	HOLD	F1				691		2880
688	HOLD	F2				692		2880
689	HOLD	F3				693		2880
690	HOLD	F4				694		2880
691	SAVEX	41	K0			695		
692	SAVEX	42	K0			696		
693	SAVEX	43	K0			697		
694	SAVEX	44	K0			698		
695	RELEASE	41				799		
696	RELEASE	42				799		
697	RELEASE	43				799		
698	RELEASE	44				799		
699	SAVEX	71	V24		BOTH	703	704	
700	SAVEX	71	V24		BOTH	705	706	
701	SAVEX	71	V24		BOTH	707	708	
702	SAVEX	71	V24		BOTH	709	710	
703	COMPARE	X71	GE	X70		711		

704	ASSIGN	25	X70			715		
705	COMPARE	X71	GE	X70		712		
706	ASSIGN	26	X70			716		
707	COMPARE	X71	GE	X70		713		
708	ASSIGN	27	X70			717		
709	COMPARE	X71	GE	X70		714		
710	ASSIGN	28	X70			718		
711	ASSIGN	25	X71			715		
712	ASSIGN	26	X71			716		
713	ASSIGN	27	X71			717		
714	ASSIGN	28	X71			718		
715	ASSIGN	*13	X66			719		
716	ASSIGN	*13	X66			720		
717	ASSIGN	*13	X66			721		
718	ASSIGN	*13	X66			722		
719	SAVEX	61	X67			723		
720	SAVEX	62	X67			724		
721	SAVEX	63	X67			725		
722	SAVEX	64	X67			726		
723	HOLD	61				727		*25
724	HOLD	62				728		*26
725	HOLD	63				729		*27
726	HOLD	64				730		*28
727	TABULATE	61				731		
728	TABULATE	62				732		
729	TABULATE	63				733		
730	TABULATE	64				734		
731	RELEASE	*13				735		
732	RELEASE	*13				736		
733	RELEASE	*13				737		
734	RELEASE	*13				738		
735	SPLIT					739	755	
736	SPLIT					740	755	
737	SPLIT					741	755	
738	SPLIT					742	755	
739	HOLD	71				743		29
740	HOLD	72				744		29
741	HOLD	73				745		29
742	HOLD	74				746		29
743	RELEASE	41				747		
744	RELEASE	42				748		
745	RELEASE	43				749		
746	RELEASE	44				750		
747	SAVEX	41+	K40		BOTH	751	799	
748	SAVEX	42+	K40		BOTH	752	799	
749	SAVEX	43+	K40		BOTH	753	799	
750	SAVEX	44+	K40		BOTH	754	799	
751	COMPARE	X41	GE	K6000		671		
752	COMPARE	X42	GE	K6000		672		
753	COMPARE	X43	GE	K6000		673		
754	COMPARE	X44	GE	K6000		674		
755	ADVANCE				ALL	594	597	
594	COMPARE	X61	E	K1		383		
383	SAVEX	67	X91		ALL	756	764	
595	COMPARE	X61	E	K2		378		
378	SAVEX	67	X92		ALL	756	764	
596	COMPARE	X61	E	K3		598		
598	SAVEX	67	X93		ALL	756	764	
597	COMPARE	X61	E	K4		599		
599	SAVEX	67	X94		ALL	756	764	
756	COMPARE	P13	E	K1		765		
757	COMPARE	P13	E	K2		766		
758	COMPARE	P13	E	K3		767		
759	COMPARE	P13	E	K4		768		
760	COMPARE	P13	E	K5		769		
761	COMPARE	P13	E	K6		773		
762	COMPARE	P13	E	K7		770		
763	COMPARE	P13	E	K8		771		
764	COMPARE	P13	E	K9		772		
765	ASSIGN	16	V27			389		
766	ASSIGN	17	V27			409		
767	ASSIGN	18	V27			429		
768	ASSIGN	19	V26			449		
769	ASSIGN	20	V26			470		
770	ASSIGN	22	V26			612		
771	ASSIGN	23	V26			633		
772	ASSIGN	24	V26			654		
773	ASSIGN	21	V26			491		

```
11    TABLE      1    30    30    50
12    TABLE      1    30    30    50
13    TABLE      1    30    30    50
14    TABLE      1    30    30    50
15    TABLE      1    30    30    50
16    TABLE      1    30    30    50
17    TABLE      1    30    30    50
18    TABLE      1    30    30    50
19    TABLE      1    30    30    50
61    TABLE      1    30    30    50
62    TABLE      1    30    30    50
63    TABLE      1    30    30    50
64    TABLE      1    30    30    50
500   TERMINATE  P
799   TERMINATE
```

The following three VARIABLES and three ASSIGN blocks are added or replace corresponding blocks when helicopters, in this case four helicopters, are added to the program.

```
12    VARIABLE   K8*F41+K4*F42+K2*F43+F44              HELICOPTER AVAILABLE
20    VARIABLE   K648/V14+V22*K3/K25+X65*K3/K25+FN15+K1    HEL REPLACE V20
32    VARIABLE   K648/V14+V22*K3/K25+X65*K3/K19+FN15+K1    HEL ADDITION
342   ASSIGN     1     V32              392                HEL REP 342
347   ASSIGN     2     V32              412                HEL REP 347
352   ASSIGN     3     V32              432                HEL REP 352
```

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